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The Cover: The Stars and Stripes, symbol of our national unity, sails the Seven Seas as the United States Navy undertakes its huge task in the United Nations' battle for freedom. Electricity performs vital services in today's Navy. Official U. S. Navy photograph

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HIGH LIGHTS . . .

Characteristics of Coaxial Lines. Data have been presented for the calculation of solid-dielectric coaxial line characteristics, particularly attenuation and surge impedance, from physical dimensions and known properties of the conducting and insulating materials. The ratio of terminal voltages as a function of the phase angle of the line has been shown for several types of load and for both dissipative and dissipationless lines; and a derivation indicated leading to a general equation for efficiency of transmission (*Transactions pages 526–30*).

Brush-Shifting A-C Motor. A method previously described for predicting the characteristics of the brush-shifting motor when the brushes are shifted to control speed has been extended to show use of the motor to correct power factor (*Transactions pages 502–06*). A final summary extends the analysis of the motor to include all possible phase positions of the voltage introduced into the stator coils from the commutator, controlling power factor and speed simultaneously (*Transactions pages 507–13*).

Rectifier Terminology. A set of terms and definitions has been assembled for the most important concepts relating to rectifiers, as an attempt to clarify the present confusion resulting from the lack of an exact terminology. "Reactance factor," one of the newly defined concepts, reduces rectifier-circuit constants to a single per-unit quantity, thus simplifying the analysis of rectifier circuits (*Transactions pages 496–9*).

Concentric Tubular Conductors. Concentric tubular circuits to carry heavy alternating currents, single-phase or three-phase, have been found to provide compactness, low reactance voltage drop, and reduced crowding of current to the surface of the conductors. Formulas for the reactance and skin effect of such arrangements of tubular conductors have been developed (*Transactions pages 513–18*).

Load-Center Unit Substations. Standard load-center unit substations have been developed to service load areas, such as buildings, mines, yards, docks, and camps, with low-voltage a-c power at utilization voltage. Tables have been provided for the selection of load-center unit substations to meet the requirements of the main types of low-voltage a-c distribution systems (*Transactions pages 519–25*).

June Supplement. The June 1942 "Supplement to *Electrical Engineering*—*Transactions* Section" will contain five technical papers and the discussions of these papers and those preprinted in the *Transactions* sections of *Electrical Engineering* from January to June 1942 inclusive; its appearance completes the publication of winter-convention papers and discussions (*page 360*).

Determining Efficiencies. Test results and analysis have indicated that the calorimetric method provides the most satisfactory over-all test of the performance of machinery under actual conditions of loading; a simplification of the classical technique has been introduced in which the important measurements are all electrical (*Transactions pages 530–2*).

Limiting Metal in Motors and Circuits. A method has been developed to determine the minimum cross section of copper and Nichrome that can be used on motors, motor control, and branch circuits to provide adequate current-carrying capacity during overload or short-circuit conditions (*Transactions pages 483–7*).

Design of Selenium Rectifiers. Characteristics of the principal sizes of selenium rectifier plates have been considered as applied to the design of single-phase, three-phase, full-wave, and half-wave rectifier units and all varieties of loading. Representative computations are included (*Transactions pages 488–95*).

Atom Accelerator. The tremendous potentialities inherent in the release of atomic energy lend additional interest to study of the mechanical and electrical problems that were solved in designing the largest of the various cyclotrons now being used or under construction to explore the atom (*pages 348–53*).

Airport Electrification. Special engineering problems were involved in adapting Civil Aeronautics Administration standards to a municipal airport of unusually large area and traffic volume, among them the development of specifications for many materials not previously manufactured (*pages 341–8*).

Fusing of Transformer Banks. Experience covering 15 years with high-voltage fusing of 11-, 22-, and some 66-kv transformer banks has shown that fuses, when applicable, are a satisfactory economical means of obtaining reasonable protection against faults in and beyond transformer banks (*Transactions pages 533–5*).

Directors' Report. The annual report of the AIEE board of directors for the year ending April 30, 1942, included in full in this issue, presents to the membership brief accounts of headquarters and committee activities and incorporates the annual financial tabulations (*pages 368–81*).

Temperature-Aging Tests. Data resulting from tests on class-A-insulated fractional-horsepower motor stators at 200, 160, and 135 degrees centigrade indicate that up to 200 degrees centigrade no abrupt change occurs in the temperature-aging curve (*Transactions pages 499–501*).

Limiter for Networks. A 600-volt totally enclosed limiter, developed for industrial distribution networks, will interrupt fault currents in excess of 50,000 amperes at 600 volts without perceptible noise or visible demonstration (*Transactions pages 536–8*).

Wind Shielding in Lines. Wind-tunnel tests on laboratory models of distribution lines show appreciable shielding of the leeward conductors by the windward conductors (*pages 354–7*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: a group of articles reflecting the high lights of AIEE summer convention just concluded; a paper on sleet problems on electrified railroads by H. F. Brown (M'25); four papers relating to lightning and lightning protection—one on abnormal currents in distribution transformers resulting from lightning by J. M. Bryant (M'13) and M. Newman (A'39); one describing the effect of lightning on thin metal plates by K. B. McEachron (F'37) and J. H. Hagenguth (A'28); one on a practical counterpoise design to protect transmission lines from lightning by E. Hansson (M'35) and S. K. Waldorf (M'36); and one describing a modern cathode-ray oscillograph for testing lightning arresters by E. J. Wade (A'23), T. J. Carpenter (A'38), and D. D. MacCarthy (A'28); a paper describing a new moving magnet instrument for direct current by H. T. Faus (M'34) and J. R. Macintyre (A'41); a group of papers on ignitrons—one on sealed-tube ignitron rectifiers by M. M. Morack (M'42) and H. C. Steiner (A'32); one on ignitor excitation circuits and misfire indication circuits by A. H. Mittag (M'40) and A. Schmidt, Jr. (A'35); and one describing an analytical treatment for establishing load-center ratings of ignitrons by D. E. Marshall (M'33) and E. G. F. Arnott; two other papers on rating of apparatus, one on current ratings of electronic devices for intermittent service by R. E. Hellmund (F'13, deceased); and one on the application of apparatus and conductors under various ambient-temperature conditions by Doctor Hellmund and P. H. McAuley (A'36); a paper describing the carbon arc as an industrial tool by W. C. Kalb (F'40); a paper on the electronics of the fluorescent lamp by Mark A. Townsend (A'42); a paper on regulated rectifiers in telephone offices by D. E. Truckses (M'40); a paper on emergency overloads for oil-insulated transformers by F. J. Vogel (M'41) and T. K. Sloat; and the third in a series of papers on the dielectric strength and life of impregnated-paper insulation by J. B. Whitehead (F'12).

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Electrification of the Chicago Airport

HARRY W. BAUMER
MEMBER AIEE

The electric system governing lights, signals, and controls for an airport with the area and traffic volume of the Municipal Airport at Chicago, Ill., presents problems not only in design, but in adapting to special conditions the standards specified by the Civil Aeronautics Administration for all United States airports. The results represent the latest practice, and include a number of unusual developments.

A YEAR ago it was my pleasure to visit the more important airports along the eastern seaboard of the United States from Boston to the District of Columbia. The one thing that each community has in common with all others, I found, is that each has the busiest airport or the largest in the world! With that experience to guide, let me deliberately avoid consideration of that particular phase in relation to Chicago's airport. The fact that Chicago continues to be the railroad center of the United States largely because of its geographical position suggests that it is also the crossroads of the nation's airlanes. Accordingly, the Chicago Municipal Airport may well become the most important landing field in this country.

For better comprehension of the many problems involved in the preparation of plans for the Chicago airport electrification project and the compilation of specifications for materials, many of which have not heretofore been manufactured previously, a description of the general location and layout of the field may be of interest. Chicago's Municipal Airport occupies an area of 620 acres—virtually one square mile from 55th Street to 63d Street and Cicero Avenue to Central Avenue, school-fund property under the jurisdiction of the Board of Education which is leased to the City of Chicago for airport purposes. The airport is situated 10.5 miles southwest of Chicago's business center, a 45-minute ride by automobile, accessible by four main traffic arteries and by two surface street car lines.

Initially only the 120 acres lying at the southeast corner of the present field were developed, by laying cinder runways and leasing small hangar lots to one or two pioneer airlines. The work was financed by small annual appropriations together with one bond issue of $450,000. With these sums the present administration building and terminal depot were built, and a concrete taxiway and four cinder runways laid. Before the development of Chicago's airport was undertaken in 1927, the ground plot on which the field is laid was a truck garden, low and swampy. This fact has necessitated laying more than 19 miles of sewer tile, constructing 550 sewer manholes and catch basins for proper drainage, and in addition providing almost 2,000,000 cubic yards of fill to raise the ground level to the present grade. From this beginning, with the aid of Federal Works Projects Administration funds, has grown the present airport.

In 1931 the administration building and passenger depot on the east side near the southeast corner of the original airport plot was built at a cost of $90,000 of the $450,000 bond issue. Because this building in the interval already has been outgrown completely, plans are now in preparation for the construction of a larger

Essential substance of an address delivered at the fall airport conference sponsored by the Illinois Institute of Technology, Chicago, Ill., October 30–31, 1941.

Harry W. Baumer, formerly engineer with the City of Chicago Electricity Bureau, in charge of the electrification of the Municipal Airport, is now on active duty as a lieutenant-commander in the United States Naval Reserve, stationed at the Navy Yard, Mare Island, Calif.

and more accessible terminal estimated to cost $2,000,000.

Chicago's airport is to date the only one in the United States having dual parallel runways. These lie in the direction of the cardinal and quadrantal points of the compass. They are spaced on 800- to 1,100-foot centers, and with the exception of the primary east-west runway, which is 300 feet in width, are 184 feet wide with an average length of 5,000 feet. They are paved with macadam. Since there are 9 runways in all, the field has 18 approaches from the air. The concrete-paved taxi strip that surrounds the field is 150 feet in width, except where it widens to 400 feet near the site of the proposed terminal buildings. The area of the paved runways and taxi strips is equivalent to a double-lane 20-foot highway 100 miles in length.

Eight major airlines are now operating in and out of Chicago, including American Airlines, Braniff Airways, Chicago and Southern Air Lines, Eastern Air Lines, Northwest Air Lines, Pennsylvania-Central Air Lines Transcontinental and Western Air Lines, and United Air Lines which has its administrative headquarters at Chicago. Pioneering in the adoption of safety measures, Chicago was the first airport at which a printed book of rules governed field operations, and it has established a record by not having had any major accident or injury to airliners or passengers on the field. The electrical facilities now under construction have for their objective the retention of this safety record.

There are periods of the day when airplanes land and take off not more than 30 seconds apart, because of the necessity of making connections at other cities. Thus the importance of the airplane controls being installed become readily apparent, especially in view of the increased traffic which must be anticipated in the years ahead. Simultaneous landings and take-offs are now common occurrences.

The electrical plan contemplates the installation not only of the customary nighttime and foul-weather aids to aerial traffic in the form of lighting, but also added signal facilities intended to provide unmistakable and effective control of airplanes, whether in the air or on the ground, equipped with radio or not, thus materially increasing the capacity of the port and minimizing the dangers associated with centralized aircraft operations.

The Civil Aeronautics Administration of the Department of Commerce has established certain fundamental, conventional electrical requirements, largely in the interest of uniformity and standardization. However, the problem of providing lighting and controlling electrical facilities at an air terminal as extensive as the Chicago airport requires not only compliance with basic CAA regulations, but the application of sound engineering judgment and recognized operating practice as well. Obviously the regulations and standards applying to airports throughout the United States are not suited in each detail to so large a terminal, and considerable latitude in the interpretation of the specifications becomes necessary. A fitting comparison may be drawn with small-town railroad way-stations and a large metropolitan railroad terminus—functionally the same, yet differing widely in scope and magnitude.

In planning the installation of the electrical facilities for Chicago's airport, the question of drainage has been important, especially in relation to that part of the installation affecting the paved portions of the field. Since substantially all pavements were in place before the electrical construction was planned, the selection of, locations for, and the methods of constructing the vaults, conduit lines, and lateral conduits have been the subject of careful and exacting study in order to reduce interference with air traffic during construction, and keep to a minimum the runway and taxi-strip openings with resultant costly pavement restorations.

Since obstructions above ground level are for obvious reasons not permissible either on the field approaches or within the limits of the landing area proper, which is that space outlined by the boundary lights, all electric cables and conductors necessary for the operation and the control of the various lighting and signaling circuits are installed in underground conduit lines. The routes established for these necessitated minimum interference with pavements, yet they are so positioned that all electric units being provided may be served conveniently and economically, remotely controlled, and maintained at minimum expense.

Approximately five miles of conduit have been built, containing from 4 to 12 ducts, which are encased in a three-inch envelope of concrete. The ducts are thin-wall asbestos cement three inches in internal diameter. The 58 vaults of reinforced concrete are spaced at intervals ranging between 400 and 500 feet in these conduit lines. Since switching equipment for remote control is being installed at runway ends, vaults at these locations are provided with sewer connections to the field drainage system. Other manholes and handholes are fitted with sumps.

Where individual circuits, such as those for boundary and runway contact lighting, pass under paved areas in all 97 locations, 2-inch heavy-walled fiber-duct laterals have been installed directly in the soil at a depth of 18 inches.

A three-phase four-conductor 4,000/2,300-volt electrical distribution cable encircling the field is being installed to serve not only the floodlights at the four field corners, but the ground and air signal lights and the illuminated runway numerals at the 18 runway ends as well. This cable feeds two ways from the airport substation and connects through transformers to the various individual load centers at points suited to distribution.

Cable sections adjacent to floodlight towers are terminated by means of disconnecting-type cable potheads electrically connected so that the cables normally form a continuous electrical circuit around the field. Should an electric fault develop in any section of this cable loop,

the faulty section can quickly be isolated. Cable requirements for this distribution circuit total 20,594 feet.

LIGHTING SYSTEM

Beacon lights at night guide aviators to their destinations and also mark the locations of fields whereon landings can be made. To outline these areas during periods of darkness and limited visibility, boundary lights are installed. These are spaced at approximate 300-foot intervals, the standard adopted by the CAA, so that pilots aloft not only can observe the field's shape but, on counting the spaces, readily can establish its proportions and extent.

The field outline at Chicago is marked by 54 white boundary lights fitted with 320-lumen 6.6 ampere series-burning lamps rated at 29 watts each. In addition to these white lights each runway extremity is marked by 4 green range lights. Two of these latter lie along the outer edges of the runway pavement and are connected in the boundary lighting circuit; the other two are positioned in the pavement in alignment with those along the edges, all being set on a line normal to the runway. The range lights are illuminated by lamps rated at 1,000 lumens, 6.6 amperes and 62.5 watts average. The position of these lights has been established upon a 20:1 glide angle, so that an airplane descending at that angle with range lights for guides in making ground contact will clear obstacles that exist outside the airport limits. Thus by directing their airplanes toward or beyond these green lights in approaching the field pilots are aided in making safe landings.

At night runways are indicated by parallel rows of lights along the pavement borders. These runway marker lights are placed opposite each other normal to runway axes on approximately 200-foot centers. These units, with the exception of their light-distribution characteristics and color filters, are identical in design and construction with the boundary lights and are illuminated by lamps of the same rating as those employed for the clear white boundary lights. Of the four green range lights marking the runway extremity, two are connected in the boundary-series lighting circuit; the other two are connected to operate only when the runway lights are in operation. Runway lights are designed to operate on asymmetric light distribution and are clear white except for those units set along the final 1,500 feet at the runway ends. These, through the use of a split color filter, produce a white light in one direction and a yellow light in the other. The yellow indication is intended to warn pilots that only a relatively short distance (1,500 feet) remains in which to bring the airplane to a stop. The boundary lighting circuit is operated continually from dusk to dawn and during other periods of comparative darkness, while the eight series runway circuits, fed by a multiple-conductor cable terminating in the control station, are controlled to operate individually as wind shifts require.

The number and width of runways at the Chicago airport and the radii of pavements at runway intersections introduce aspects of the problem of illuminating runways not met with in other installations, rendering standard luminaires unsuited and requiring design changes. The revised luminaire design is planned for economy in both installation and operation. Since series circuits are being employed for boundary and runway contact lights, where units are positioned within the paved areas but outside of the runway intersections proper, normally a lateral conduit would be provided for each unit, a separate lateral for the cable crossing under the pavement of the intersecting runway, and a third lateral for the unit at the far side of the runway pavement. Cable then would be installed to the first unit looping back, then brought through the lateral crossing the runway and another loop into the light at the other side of the pavement. This type of installation would involve not only added first cost for lateral and cable and increased copper losses during operation, but difficulty and expense in locating cables should cable faults develop. Through the use of slightly enlarged cable-entrance hubs on luminaires capable of accepting the two-inch diameter laterals and providing a continuous duct in the light housing it becomes feasible to install a single cable connection between units at runway intersections, by rodding the lateral straight through both lights onto the other side of the pavement. Hence no uncertainty need present itself as to where the cable connecting the unit at intersections lies, because the lateral is continuous from one pavement edge through the lights to be connected on the same circuit and beyond to the other pavement edge.

The luminaires employed for boundary and runway marker lights are flush-type, the housings being set down in concrete or in the runway pavements so that after the units are completely assembled the prismatic lens and cover do not project more than two inches above the grade. The lenses are designed and made of strong heat-resisting glass so that an airplane wheel striking one of them on landing or take-off will not readily cause damage either to the unit or the airplane. Suitable gaskets are provided to prevent the entrance of water into the light housings. The lower portions of these flush-type lighting units are sealed by means of compound similar to that used in making cable joints to exclude water from below. Each series-burning light, including the boundary and runway-marker light units, is fitted with the conventional film cutout used in street-lighting practice, so that when a lamp burns out, opening the circuit, the film breaks down, re-establishing the circuit until the lamp replacement has been made and a new film disk has been inserted.

The 428 runway or boundary lights are connected by 20 miles of single-conductor number 8 rubber-insulated and rubber-armored cable designed for 3,000 volts operating potential. This cable is laid 18 inches below the 3-foot wide white-top cement strips laid alongside each

runway edge as a marker, making the pavement limits more easily distinguishable from the air.

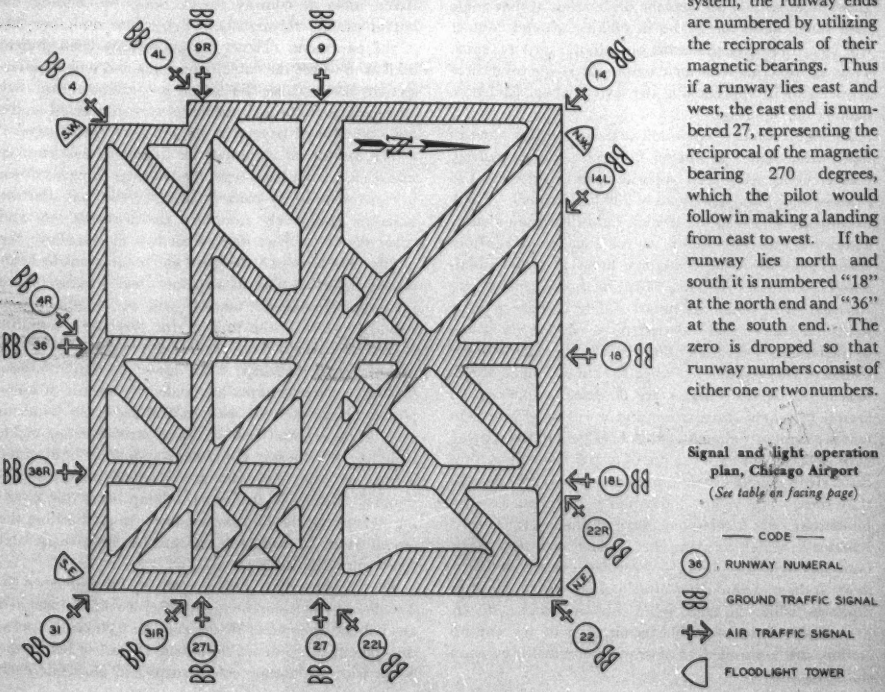
To supplement the lighting described, landing-area floodlights are being installed to produce illumination assisting pilots in judging altitude and distance, both so important in night landing. Four floodlight towers for mounting the floodlight banks are offset somewhat from the quadrantal runway axes, one at each corner of the field. Modernistic in architectural treatment, the towers are 22 feet high and 14.5 feet wide, the horizontal plan being in the shape of an equilateral pointed arch, the curved portions forming two sides, the faces being recessed for the entrance doorways and for mounting the floodlight lens frames. These structures are built of brick masonry finished with white cement plaster. The upper decks, 10 feet above grade, are for the installation of the optical systems of the floodlights, while the entrance steps at ground level are to house the electric equipment feeding and controlling the floodlights. The towers are marked as hazards by red obstruction lights operated through relays connected in the boundary lighting circuit.

Each bank of floodlights consists of 16 500-millimeter 90-degree Fresnel lenses, lighted by the same number of 1,500-watt 32-volt multiple incandescent lamps with monoplane filaments and Mogul bipost bases, which are capable of producing 42,000 lumens each and have a rated life of 100 hours. In addition to the lenses and lamps, metallic spherical mirror reflectors subtending angles of approximately 110 degrees complete the floodlight optical systems. Thus the connected lamp load at each of the four floodlight towers is 24 kilowatts. Each bank of floodlights is guaranteed to produce an illumination intensity of 0.3 foot-candle in the vertical plane at a distance of 3,000 feet. Thus each quadrant of the landing area is amply illuminated by the floodlight bank adjacent to it.

Double-hung hinged doors made of Transite enclose the floodlight lamp compartments within the building so that the exhaust fans for ventilating and cooling the lamp chambers can circulate the air which is admitted through screened louvers at the bases of these enclosures and discharged through others near the top. Remote-control oil switches operate the floodlights.

RUNWAY DESIGNATIONS

The Chicago airport was one of the first to employ the recently adopted revised system of runway designations. Under the new system, the runway ends are numbered by utilizing the reciprocals of their magnetic bearings. Thus if a runway lies east and west, the east end is numbered 27, representing the reciprocal of the magnetic bearing 270 degrees, which the pilot would follow in making a landing from east to west. If the runway lies north and south it is numbered "18" at the north end and "36" at the south end. The zero is dropped so that runway numbers consist of either one or two numbers.



Signal and light operation plan, Chicago Airport

(See table on facing page)

The adoption of this standard reduces air congestion at the airport since pilots upon receiving landing instructions by radio before they are in sight of the field are told what compass direction to follow in approaching the airport in order to land straight ahead. The advantage of this system is evident under conditions of reduced visibility, when numbers are not clearly visible from the air.

Numerals 50 feet in length, of reinforced concrete with white cement surfaces, are placed horizontally on the center lines of each runway end, slightly sloping from the field, being raised 1 foot above grade at the edge nearest the field and 6 inches at the edge farthest from the landing area. The vertical strokes of those numbers are 4 feet in width while the horizontal strokes are 8 feet wide so that they are clearly visible from an altitude of at least 500 feet in ordinary daylight. While ready identification of runways is important under daylight conditions it is vastly more so at night when additional landing hazards are introduced. Hence the numerals are illuminated by 1,600 lights placed on 2-foot centers on the upper faces of the numbers along the center lines of the strokes. The vaporproof fixtures utilized for these lighting units are anchored to the concrete and connected by means of iron-pipe conduit and fittings through which the connecting wires are brought.

SIGNAL SYSTEM

Since the rapidity with which airplanes are dispatched in arriving and departing is important and doubtless will become increasingly so during the next decade, a system of visual signals has been installed for control of airplanes whether they are in the air or on the ground, intended to supplement and to co-operate with radio control. At the end of each runway, behind the numerals just described and close to the fence lines, ground signals with one red, two green, and one clear white target in signal-enclosing heads are mounted seven feet from the ground on iron-pipe standards set on concrete bases and designed to give indications to airplanes on the runways.

To signal airplanes in the air a two-color (red and green) signal has been developed, which is visible only from the air during day or night. These signals are placed at the heads of horizontal white cement arrows pointing toward the runways. The arrows with shafts 90 feet long, 4 feet wide, and heads that measure 42 feet between barb-tip extremities, are laid on the runway center lines. The light signals mounted on them indicate by a green light that the runway is clear for landing and by a red light that it is closed for landing operation. The arrows are set outside the concrete taxi strips but ahead of the runway numbers.

The 120-volt feed for these lights is obtained from transformers installed in the floodlight towers and connected to the 2,300 volt primary distribution circuit. For controlling these signal lights and runway numerals, six multiple-relay switches in a submersible-type case are installed in the vault nearest the equipment to be operated at each of the 18 runway ends.

Multiple-conductor cables installed in the conduit lines are provided for the operation of these relay groups and the floodlight-control oil switches. Energy at 120 volts 60 cycle for relay and oil switch operation is supplied from a transformer connected to the bus in the airport substation and transmitted to the relays and switches over the multiple-conductor control cables, the

Signal and light operation plan, Chicago Municipal Airport

(See diagram on facing page)

Landings

Wind direction	N	N	NE	NE	NE	E	E	SE	SE	S	S	SW	SW	SW	W	W	NW	NW
Illuminated runway numeral—night only	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Air traffic signal—green	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Near end ground traffic signal—red	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Runway lights night only	18L	18		4	4L	9R	9	14	14L	18	18L	22R	22		27	27L	31R	31
	36R	36		22	22R	27L	27	31	31R	36	36R	4L	4		9	9R	14L	14
Floodlights night only	SE	SE or SW	SE	SW	NW or SW	SW	NW or SW	NW	NW	NE or NW	NE	NE or NW	NE	SE	SE or NE	SE	SE or NE	SE

Take-Offs

Wind direction	N	N	NE	NE	NE	E	E	SE	SE	S	S	SW	SW	SW	W	W	NW	NW
Air traffic signal—red	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Near end ground traffic signal—green	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Far end take-off signal—green	18L	18	22L	22	22R	27L	27	31	31R	36	36R	4L	4	4R	9	9R	14L	14
Runway lights night only	18L	18		4	4L	9R	9	14	14L	18	18L	22R	22		27	27L	31R	31
	36R	36		22	22R	27L	27	31	31R	36	36R	4L	4		9	9R	14L	14

Emergency Stop*

Air traffic signal—red	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Near end ground traffic signal—red	36R	36	4R	4	4L	9R	9	14	14L	18	18L	22R	22	22L	27	27L	31R	31
Far end ground traffic signal—red	18L	18	22L	22	22R	27L	27	31	31R	36	36R	4L	4	4R	9	9R	14L	14

* On emergency stop, runway and floodlights if operating continue in operation.

individual relay and switch circuits being completed through the common return wire.

POWER SUPPLY

The airport substation and control center is centrally located, in a position readily accessible for connection to the feed of the Commonwealth Edison Company, which furnishes electric service for the airport. The design of this structure represents a compromise between an underground vault and the conventional building at grade. Because of drainage problems the former was not deemed feasible; since the latter introduced air hazards it was not applicable. The building of monolithic concrete approximately 25 by 35 feet in plan with ceiling height 8 feet 6 inches extends 6 feet above ground level and $3\frac{1}{2}$ feet below grade. Windows provide ventilation and the advantage of daylight in the substation is gained. To guard against failure of service the company furnishes three separate 4,000/2,300-volt lines into this station, two of which originate at its own substations, while the third is brought into the city from a substation of the Public Service Company of Northern Illinois. If service interruption should occur on the normal supply it would be of merely momentary duration, because the three lines terminate at automatic oil switches electrically interconnected so that upon failure of the one feed another is automatically thrown on, and should this one be interrupted the third is then placed in operation. After the faults on the lines have been cleared, service automatically reverts to the normal feed.

Connected to this supply is the airport substation bus which is protected by a three-pole manually operated 15,000-volt 600-ampere oil circuit breaker having an interrupting capacity of 100,000 kva, fitted with overload protection and capable of being isolated from the supply through airbreak disconnect switches. Two 6.6-ampere constant current transformers, one to serve the boundary lighting circuit, the other the runway lights, are connected to this bus through fused primary cutouts and operated by remote-control oil switches. A general-service multiple transformer for station lighting and switch operation is also connected to the station bus. Both legs of the primary distribution circuit terminate at cable-end bells where the individual conductors are connected to fused disconnecting switches tied to the station bus. By this means the field supply circuit can quickly be isolated if trouble develops in it, while the boundary and runway lights continue in operation. After the fault has been cleared by disconnecting the faulty cable section or equipment causing the interruption, service can promptly be restored by again closing the fused disconnect switches.

The secondary of the constant current transformer energizing the runway lighting circuits is connected to an autotransformer and remote-control oil switches in such a manner that the runway light intensity can be adjusted to prevailing atmospheric conditions by operating the circuits at 6.1 amperes "dim" on exceptionally clear nights, at 6.6 amperes "normal" on average nights, and at 7.1 amperes "bright" when visibility is poor. The runway-lighting multiple-conductor feeder cable is connected to eight remote-control oil switches, one for each runway lighting circuit. A 24-cell lead storage battery for actuating the remote-control electric equipment is included in the station equipment.

Although the automatic control is considered very reliable, a manual control consisting of a single-pole double-throw switch for each circuit has been installed to permit the individual control circuits to be disconnected from the automatic system and operated manually from the substation if for any reason the automatic equipment fails to function.

CENTRALIZED CONTROL SYSTEM

In order that the various airport signals and other lighting facilities may be operated from the control tower and readily adjusted to the prevailing wind and weather conditions as frequently as may be necessary, and in the combinations for day and night take-offs and landings an unusual system of control is being installed. This method rather than the manual interlocking direct control commonly employed is being adopted to effect the necessary field signal operations during daylight hours, as well as both the signal and lighting arrangements for airplane movements at night and in periods of poor visibility, with minimum effort and reduced chances for error, through the elimination of the human element as far as possible. The present volume of traffic at the Chicago airport, the increase to be anticipated in the years to come, the number of air approaches to the field with its parallel and intersecting runways, and the many signal indications with their complex combinations deemed necessary to expedite field operations, warrant selection of equipment of proved reliable and sufficient flexibility to insure response under any circumstances likely to be encountered in service.

Switching apparatus similar to that employed on automatic telephone systems has been selected because of its dependability, compactness, and long life. The apparatus proposed consists of a control panel for installation in the central tower which is linked with a relay and selector switch rack in the substation by means of a 220-pair lead-covered cable. This equipment is actuated by the 48-volt lead storage battery installed in the substation battery room. Direct current is necessary for this service to insure prompt, positive impulse-switch and relay operation.

The operating switches mounted on the lower portion of the tower operating panel consist of 21 switchboard lever-type cam keys, 1 each for controlling the airport beacon, the wind tee, the boundary lighting circuit, the runway light brightness control, 3 groups of 4 keys each for field signal and light control and 5 keys for the operation of the 4 floodlights. Eighteen push keys

grouped in the lower left-hand corner, an impulse dial for runway selection in the lower right-hand corner, and a terminal block for the cables which connect the operating-indicator panel in the tower with the relay-switching equipment at the substation complete the panel assembly.

The remote-control relay rack, an angle-iron structure one foot by four feet by nine feet high erected in the substation, carries approximately 150 power-type relays, 35 fast-acting telephone-type relays, 6 25-point rotary switches, 2 11-point rotary switches which are interconnected, and fuse protection for the operating-control relay circuits.

The remote controls are the nerve center of the airport electric system, assuring the dispatcher that certain lights and signals in the field are in operation even though he may be unable to see them from his position in the tower. The manually operated equipment of the tower panel, being electrically connected with the automatic switching apparatus, actuates the remote-control relays and switches in the substation. After the establishment of the electrical connections that close the circuits to the switches energizing the field lights and signals that are being placed in operation, "telltale" indicator lamps behind the translucent portions of the tower control panel, corresponding to the signals and lights being illuminated, are lighted to indicate what light units are in operation.

Any description of the airport's electrical facilities and their functioning would be incomplete without an explanation of the co-ordinated operation of the lighting and signaling systems.

When an airplane arrives in the zone under the airport dispatcher's jurisdiction, the pilot announces his position by radio, referring to known landmarks and signifying his intention of landing. The dispatcher informs the pilot of the wind direction and velocity, and if the visibility is limited that information is also given. From the position of the anemoscope indicator on the control panel, the dispatcher observes runway numbers suited for landing or take-off.

If, for example, the wind is from the south, runways 18 and 18L are favorable and thus preferred. The pilot is instructed to land on runway 18. The dispatcher moves one of the left-hand cam keys of the three groups on the control panel to the lower "select" position and using the "runway selector" he dials number 18. The lever key then is returned to the mid- or "hold" position and immediately the number 18 at the right of the switch group being operated illuminates, indicating that signals and lights for landing or take-off on runway 18 can now be placed in operation by manipulating other switch keys of that group. If it is daytime the right-hand lever key of the group is set to the upper "day" position, permitting the operation of air and ground signal lights only. Up to this point no field units have been energized.

The airplane which has been announced is now near or over the field; the pilot reports his presence; and as he approaches for a landing the dispatcher operates the center key to the down "land" position. Immediately the illuminated runway numeral 18, the green air signal, and the red ground signal are placed in operation. The pilot observes the signal and number and makes the landing. Pilots of airplanes on the ground are warned by the red field signal to keep clear of the runway.

The same operating procedure applies for night landing, except that the right-hand key is set to the lower "night" position; then when the center key is turned to "land" in addition to the signals as for day landings, the contact lights along runway 18 are placed in operation, as well as the floodlight bank at the northeast corner of the field.

Most airplanes in use today can be landed and halted before reaching the mid-field. To clear runways as quickly as possible, the pilot is directed by radio to follow the white flashing ground signal. These lights are individually controlled by the push keys on the panel. They operate only as long as the keys are depressed.

The pilot of an airplane desiring to take off reports to the tower by radio; the dispatcher then gives the wind velocity and direction, and after referring to the anemoscope on the control panel indicates the runway to be used. The airplane then is maneuvered on the taxiway along the outside of the landing field to a position along side the runway assigned to take-off.

The dispatcher after selecting the runway in the manner already described for landing, sets the right-hand switch key for day operation if take-off is by day. With the airplane near position to take off and conditions on the field and over it satisfactory, the operator throws the middle cam key to "take-off." The red air signal near the plane taking off and the green ground signal at the near runway end are illuminated. The airplane is taxied into position and takes off. The red air signal warns airplanes aloft not to approach and the green ground signals give clearance to the one taking off.

Should an emergency arise or a faulty interpretation of signals be made by a pilot in either landing or taking off, so that an accident is imminent, the dispather can nullify his previous signal by operating the single red key of the group to the "emergency stop" setting, which disconnects the signal lights in operation and lights instead the red air signal and both the near and distant red ground signals. Thus the pilot of an airplane in the air, observing the red air signal, remains aloft and does not attempt a landing and one on the ground awaits further instructions from the tower before proceeding.

Three identical key groups on the tower control panel for runway selection are provided. By two of these, parallel runways may be controlled simultaneously, while the third allows the operator to have an alternate runway selection in reserve if a shift in the wind direction requires a change.

The circuit arrangement on the control system is such that the runway selector dial can be effective on only

one control group at a time, even though two or three left-hand keys should be operated to the "select" position. Provisions are also made in the circuit to prevent the selection of a runway that already has been selected by another control group, and to prevent any selection in case a number other than a runway designation is dialed. Moreover, the center and right-hand keys may be preset before dialing. In such case none of the lighting or signaling circuits will be completed before the left-hand key is returned to its normal "hold" position after the completion of the dialing operation.

To clear any one of the three groups preliminary to making another runway selection, the operator manipulates the left-hand key to the "release" setting, which clears the key group and de-energizes the relaying equipment, leaving it in condition for another selection. Since only parallel runways can be energized at the same time, it is impossible to energize intersecting runways or give conflicting signals.

Since the electric system of the Chicago airport comprises 158 individual signal and light circuits, operated in 104 separate combinations, the utility of the automatic control system can be appreciated. The electrical facilities have been designed to permit airplane movements to occupy virtually the undivided attention of the operator. With only a moment's glance at the illuminated control panel he can determine instantly which signals and lights are in operation, or ready to be placed in operation. With the exercise of ordinary precaution by pilots, it is believed that airplanes may be brought in and taken up from Chicago's airport with greater safety, security, and dispatch than at any other airport.

The Cyclotron

W. M. BROBECK

Possible relationships of the cyclotron to future engineering developments are considered in this article, which describes the development of atomic accelerating devices, the operating principle and construction of a typical cyclotron, and the uses to which it is now being put.

IT OFTEN HAPPENS that apparatus built for scientific investigation is the forerunner of equipment used in industrial plants. Because of this possibility for the cyclotron and because of the unusual electrical problems involved in its construction, a description of it should be of interest to electrical engineers.

The cyclotron is a device for the production of a beam of atoms traveling at high velocity. Its practical value arises from the effects of the impact of the atoms of the beam on the atoms of the material of the target which the beam strikes.

TYPES OF ATOMIC ARTILLERY

In 1919, Ernest Rutherford discovered that the collision of helium and nitrogen atoms resulted in the production of hydrogen atoms. In these experiments the helium atoms were obtained from the natural disintegration of radium and had kinetic energies of five to ten million electron-volts. As a result of the scientific importance of the transmutation of elements, a great demand arose for apparatus to accelerate atoms in larger quantities and to higher speeds than were obtainable from the radiation of naturally radioactive material. This demand has given rise to the development of several types of atomic accelerators, of which the cyclotron is the most powerful.

Fortunately the acceleration of atoms is basically a very simple process. The atoms of a gas, such as heavy or light hydrogen or helium, are generally used. The first step is to perform the process of ionization, which in the case of the gases mentioned means the removal of the electrons from the neutral gas atoms, leaving the positively charged nuclei. These nuclei are the actual bullets that are projected at the target under bombardment. Ionization usually is carried out by running an arc discharge in a confined space at a pressure of the order of 10^{-3} millimeter of mercury. In the arc the electrons are stripped by collision from some of the gas atoms, which subsequently diffuse through a small opening into the high vacuum of the accelerating chamber. A lighted filament is usually one electrode of the arc. The useful ion current, consisting of the bare nuclei of the element to be accelerated, is generally of the order of 100 microamperes, but may be "contaminated" with many times as many unwanted molecular ions and incompletely ionized atoms.

Acceleration of the ions is done most simply by maintaining the ion source at a positive potential with respect to the target. Such an accelerator is illustrated diagram-

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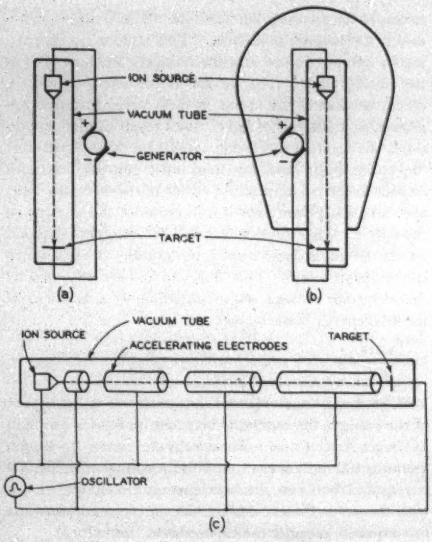

Figure 1. Types of linear accelerators

a. Conventional single stage b. Pressure insulated single stage c. Multiple stage

matically in Figure 1a. The ions "falling" through the potential drop gain kinetic energy proportional to the product of their charge and the voltage difference through which they have passed. As the charge of the electron is a convenient unit, the energy is expressed in electron-volts. Hydrogen, having a one-electron charge, reaches the target with one electron-volt of energy per volt of potential difference, while helium, having a charge of two, attains two electron-volts per volt of potential difference.

As the energies per atom necessary to produce disintegrations of the target elements are of the order of a million electron-volts and higher, the problem in designing practical accelerators of the type described is to obtain the necessary high voltage. Above a million volts, insulation becomes very difficult. As a means of reaching higher voltages, the most recent accelerators of this type have been built inside tanks in which the air pressure can be increased to from 75 to 100 pounds per square inch, with corresponding ability to hold higher voltages than at atmospheric pressure. Figure 1b is a diagram of such a device. With this construction it is also possible to control the humidity of the air, or to use other gases, such as Freon, which permit still higher voltages. With such apparatus, ions have been accelerated up to 3,500,000 electron-volts and probably double that energy is possible in the near future. Power supplies for these accelerators are usually the Van de Graaff type, in which static charges are carried from ground to the insulated electrode by moving belts, in a modernization of the old "static machine" principles.

Another method of avoiding the difficulties inherent in high voltages is to apply a lower voltage a number of times in succession. One form of apparatus using this method is illustrated in Figure 1c. Voltage is applied to hollow electrodes by an oscillator at such a frequency that, as the ions cross each gap, the electrode ahead of the ion is always negative with respect to the electrode behind it. To make use of a single frequency, the electrodes are made successively longer, so that the ions take the same length of time to pass from each gap to the next as they are accelerated. Although this device avoids high voltages, it has not proved very practical, owing to the difficulties of transmitting high-frequency power and the long lengths that would be necessary for high energies.

THE CYCLOTRON PRINCIPLE

The cyclotron also makes use of the repeated application of a comparatively small voltage, but because of important differences from the linear type of apparatus just described, it has proved a practical means of obtaining the highest energies yet reached in the artificial acceleration of atoms. A diagram of the cyclotron is shown in Figure 2. In the cyclotron the acceleration takes place in a strong uniform magnetic field between the circular pole tips of a large electromagnet, the effect of which is to cause the ions to move in circular paths. The two accelerating electrodes are semicircular and hollow with the facing sides open, and the ion source is at the center of the gap between them. Alternating

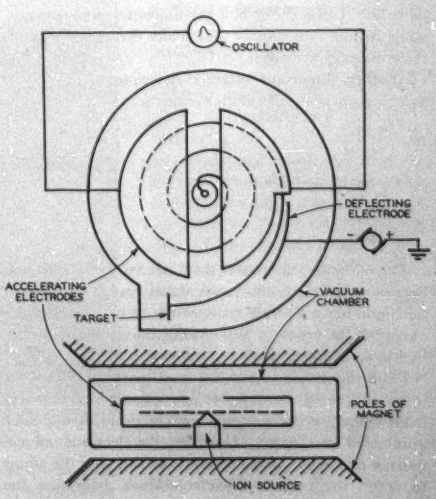

Figure 2. Schematic diagram of the cyclotron

voltage is applied across the electrodes by an oscillator at a frequency of the order of ten megacycles.

At the outside edge of one of the electrodes is an opening, beyond which is a deflecting plate supplied with a d-c voltage. The operation can best be understood by considering the journey of a single ion. When the ion leaves the ion source, it is attracted immediately toward whichever electrode is negative at the time. As it accelerates, it moves along a circle so that after half a turn it again reaches the gap. The frequency of the oscillator is set so that in the time required for the ion to travel the half circle the polarity of the electrodes has reversed and the ion is accelerated through the voltage difference between them and starts another semicircle of larger radius. As the increase in radius is proportional to the increase in velocity, the same time is always required for a half circle, so that the ion always finds itself approaching the negative electrode, and the acceleration continues until the outer radius of the electrodes is reached. Here the ion passes through the slot in the outer wall of one electrode into the electric field of the deflecting plate, which draws it farther from the center and directs it toward the target.

The operation is based on the resonance between the rotation of the ions and the frequency of the oscillator. This relation can be expressed as follows (symbols are explained in list at end of article):

$$f=\frac{1.52\epsilon H}{M}$$

In the case of the acceleration of heavy hydrogen ($\epsilon=1$ and $M=2$), f becomes ten megacycles for a magnetic field of 13 kilo-oersteds. Light hydrogen requires twice the frequency or half the magnetic field strength, while helium ions require practically the same values as those of heavy hydrogen.

Another important relation determines the energy as a function of the size of the cyclotron:

$$W=\frac{\epsilon^2H^2R^2}{3{,}240\ M}$$

or, for heavy hydrogen:

$$W=\frac{H^2R^2}{6{,}480}$$

The 60-inch cyclotron at the University of California, Berkeley, the largest now in operation, runs at 13 kilo-oersteds and has a 25-inch accelerating radius, making the energy of the beam 16 million electron-volts when heavy hydrogen is accelerated.

From the simple theory as stated there would appear to be no limit to the possible multiplication of the electrode voltage, a lower voltage merely requiring a greater number of revolutions. However, the electrode voltage must in practice exceed a definite minimum for the atoms to reach the target. Two conditions determine the minimum accelerating voltage required. The first is the necessity for focusing the ions into the median plane between the magnet-pole faces. This is done by decreasing by one or two per cent the magnetic field strength at the outer radius. The second is the effect of the increase in mass of the atoms as they travel at speeds approaching the speed of light. As a result of these conditions, the resonance relation cannot be maintained over the entire path, and the ions must gain or lose with respect to the rotation of the vector of the electrode voltage. As this phase error is a function of the number of revolutions and cannot exceed 90 degrees (beyond which the ion is decelerated), the number of revolutions is definitely limited. This limit can be best expressed by the electrode voltage required, which is a function of the final energy of the beam:

$$V=\frac{236W^2}{M\epsilon}$$

Since the voltage required thus increases as the square of the energy, the oscillator becomes more of a problem in larger cyclotrons. To accelerate heavy hydrogen atoms to 100 million electron-volts, a voltage of 1,200,000 is required between the accelerating electrodes. Even with the most efficient design, several hundred kilowatts are required to excite the electrodes at this voltage.

A TYPICAL CYCLOTRON

Each of the 30 or so cyclotrons now being built or in operation in the United States and elsewhere has been designed independently, so that it is hardly possible to discuss typical cyclotron construction. However, the 60-inch cyclotron at the University of California (Figure 3) is an example of one of the ways in which the various mechanical and electrical problems inherent in this apparatus have been met.

The largest part is, of course, the magnet. As cyclotron size is generally expressed by the diameter of the tip of the magnet poles, the dimension in this case is 60 inches. The magnet core is 16 feet long, 11½ feet high, and 6 feet wide, and is assembled from 2-inch plates for the rectangular frame, with 10-inch-thick disks for the poles. The weight of steel in the core is 190 tons. The magnet is wound with 22 tons of ½ by 2⅞ copper strip in 12 spiral coils, 6 on each side of the gap. The coils are immersed in oil circulated through a heat exchanger in a 200-gallon-per-minute cooling tower. Power is supplied by a 75-kw motor-generator set, the excitation of which is controlled through an electronic circuit which holds the magnet current to one part in 5,000.

The system supplying the voltage to the accelerating electrodes consists of a rectifier with its power transformer and control, a vacuum-tube oscillator, transmission lines, and the electrode supports and housing. A circuit diagram of the complete system is shown in Figure 4. Four hundred and forty-volt three-phase power is supplied through the main contactor to a monocyclic constant-

current network with Pyranol capacitors and fixed iron-core reactors. The number of capacitors in circuit can be varied through relays for voltage control. The voltage is stepped up to 17,000 and applied to a six-tube three-phase rectifier. The rectifier tubes, of the glass mercury-pool type, are "home made" and have been the subject of much experimentation. Two hundred kilowatts at 20,000 volts d-c can be applied to the plates of the oscillator tubes, which operate in push-pull. These tubes, also made at the laboratory, are continuously pumped and have water-cooled filament supports and grids, as well as water-cooled anodes. The circuit components consist of a resonant line-grid circuit and a coil and variable capacitor in the plate circuit. The transmission lines to the cyclotron proper are made of concentric copper tubes having diameters of 2 and 15 inches and are connected to the oscillator tubes through vacuum capacitors. The tubular supports for the accelerating electrodes inside the vacuum are made the proper length to resonate at the operating frequency, so that their outer ends, being at a voltage node, can be supported rigidly without the use of insulators. The connections from the transmission lines are made through insulators which are subjected to only a small fraction of the voltage appearing on the electrodes. As large radio-frequency currents circulate on the surfaces of the electrodes, supporting tubes, and housings, these surfaces are covered with copper sheet to which water-cooling tubes are soldered. The entire power input of 200 kw maximum to the oscillator must be carried away through the water-cooling system.

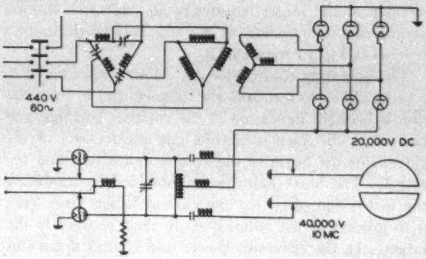

Figure 4. Circuit of the oscillator and its power supply

As the accelerating process must proceed under vacuum, which also acts as insulation against the high voltages developed, the entire system must be contained in a vacuum-tight envelope, familiarly referred to as the "tank." This consists of a bronze casting between the magnet poles, the top and bottom covers of which are of iron and act as extensions of the magnet poles, and welded steel tubes outside the magnetic field. Some 70 ports and fittings, all sealed with double rubber gaskets, are used for access and connections to electric and cooling circuits. With the oil-diffusion pumps used, the volume of 120 cubic feet can be pumped down to the required vacuum of about 10^{-5} millimeter of mercury in three hours.

The ion source uses a tungsten filament of 80-mil diameter heated by 200-kilocycle current to prevent its failure from mechanical forces resulting from operation in the magnetic field. As the life of the filament averages only about ten hours, it is removed through a lock without breaking the main vacuum. Deflection of the beam is produced by a deflector plate maintained at 100 kv by a voltage-doubler circuit immersed in oil. The plate is cooled by circulating through it the oil used for insulating its power supply. The deflector plate is supported by a tube insulated from and mounted inside one of the accelerating-electrode support tubes, so as to be shielded from the radiofrequency field of the accelerating electrode.

The target against which the atomic beam impinges is mounted in a subsidiary chamber provided with a gate that can be closed to permit changing targets without breaking the main vacuum. As the beam current at times reaches 300 microamperes at 16 million volts, the corresponding 4.8 kw de-

Figure 3. The 60-inch cyclotron at the University of California

The magnet frame and housings for the electrode supports can be seen. The rectangular boxes above the magnet are the enclosures of the resonant grid line and the oscillator. Temporary pumping apparatus is in the foreground

veloped at the target requires rather elaborate cooling arrangements, especially as the specific heat dissipation reaches 10 kw per square inch.

The operating controls for the cylotron are located in a room about 40 feet from the magnet, and to this position is brought indication of the voltages, currents, and powers in the various circuits and particularly of the current in the beam of high-speed atoms reaching the target. The latter indication is obtained by insulating the target and observing the current which flows from it to ground as the atoms give up their charges to the target. In the electronic power and control apparatus associated with the cyclotron, over 50 vacuum tubes are used for various purposes.

The radiation produced while the cyclotron is in operation, and from the targets and any other parts struck by the beam, necessitates precautions against danger to the operators. The cyclotron itself is surrounded on the sides and top by tanks of water from $3^1/_2$ to 5 feet thick to stop the radiated neutrons. In addition, several inches of lead shielding are used in some places. "Active" targets that have been bombarded recently must be handled at a distance and stored in radiation-absorbing enclosures. In addition, the operators carry instruments to record their exposures.

THE 184-INCH CYCLOTRON

The 60-inch cyclotron at the University of California has been in operation since March 1939, and often has run 24 hours a day for considerable periods, owing to the demand for radioactive materials and for its use in medical, biological, and physical experiments. Its success and the promise of new discoveries at still higher energies made the construction of a much larger cyclotron appear possible and desirable. Accordingly, with a grant from the Rockefeller Foundation, the University of California is proceeding with the construction of a cyclotron having a pole-tip diameter of 184 inches. An artist's sketch is shown in Figure 5. The magnet will stand 30 feet above its base, be 56 feet long, and contain 3,700 tons of steel and 300 tons of copper. An initial installation of 2,500 kw for the oscillator and 400 kw for the magnet is to be made. Completion of the magnet is scheduled for the spring of 1942, and it is hoped that the complete apparatus will be in operation by the summer of 1943. An atomic beam of 100 million volts energy is expected from this cyclotron. Such a beam has a penetrating power of 140 feet of air, compared to about 5 feet for the 16-million-volt beam of the 60-inch cyclotron. The potentialities of such energy in atomic disintegration appear to be considerable.

Figure 5. Artist's sketch of the 184-inch cyclotron now under construction at the University of California

USES OF THE CYCLOTRON

Although this article is concerned primarily with the engineering features of the cyclotron, some consideration also may be given to the purposes served by thus building apparatus weighing thousands of tons. To make clear the uses of the cylotron, it is first necessary to explain the sort of radiation that is produced when the atoms of the beam collide with those of the target at speeds approaching the velocity of light.

The important part of the atom is the nucleus, which even in the densest materials occupies only an infinitesimal proportion of the volume of the substance but which determines the nature of the element. The particles of the beam from the cyclotron, usually consisting of the nuclei of hydrogen atoms, penetrate the material of the target to a depth of a few millimeters, and perhaps one in a million makes a hit on a nucleus of an atom of the target material. (The remainder are brought to a stop by collisions with electrons, which do not concern us here.) In the collision, the atomic projectile appears to be captured by the target nucleus, and very often a piece of nuclear matter, that is, one or more protons or neutrons, is given off. When the weights of the particles captured and emitted are considered, the result shows that the atoms of the target must have been changed to those of another element or another form (isotope) of the same element. However, this weight calculation usually reveals a small discrepancy of the order of 1/10,000 of the total weights of the particles involved, and this difference, converted into equivalent energy units by the use of the relation between mass and energy, can be shown to appear

as the difference between the kinetic energies of the bombarding particle and the products of the collision.

The emitted neutrons, having no electric charge, possess great penetrating ability, comparable to that of X rays, while the protons, being similar to the bombarding atoms, can be stopped by a few millimeters of solid material. Moreover the neutrons can again act as bombarding projectiles on other targets, and this results in secondary transmutations. Self-sustaining chain reactions of this type, releasing appreciable quantities of atomic energy, are theoretically possible and constitute one strong reason for the encouragement of research at higher bombarding energies.

The new elements or isotopes may be formed in an unstable condition, from which they eventually will return to a stable form. This return is accomplished by the ejection of a positive or negative electron and often results in the production of high-energy X rays or gamma rays. This process is the same that occurs naturally in radium and its derivatives; hence it is called artificial radioactivity. Such radioactive substances can be followed through any physical or chemical changes by observing their emitted radiation. This use of radioactive atoms as tracers has caused them to be popularly known as "tagged atoms." By bombarding available target materials, it is possible to obtain all the 92 elements in radioactive form and even to prepare the radioactive form of what is almost certainly element 93.

These atomic phenomena are the basis of the use of the cyclotron in the fields of physics, medicine, physiology, and biology. In physics, the study of the forms and behavior of the nuclei of atoms is an extremely broad field, dependent to a large extent on the cyclotron. In medicine, the cyclotron is used in the production of neutron rays directly from the target under bombardment for experiments in cancer treatment. Radioactive materials made by the cyclotron are given to patients to expose the body to internal radiation. In physiology and chemistry, the use of artificial radioactive substances as tracers in life processes and reactions, where groups of atoms must be differentiated from others of the same element, has been of great value in studying such problems as the absorption of fertilizers from soil and the action of plants in synthesizing carbon dioxide and water into carbohydrates. Just as atomic projectiles are used in discovering the structure of the atomic nuclei, they are also of value in studying the nuclei of cells through the effects of the damage and rearrangement caused to the cell parts on exposure to radiation. (See also "Atom Smashing and Its Applications to Medicine," Robley Evans, *Electrical Engineering*, volume 60, June 1941, pages 250–60.)

FUTURE OF THE CYCLOTRON

Up to the present, the cyclotron has been used principally on scientific rather than engineering problems. Its importance to engineering appears to be in the future development of the scientific fields to which it contributes. Metallurgy and chemical engineering undoubtedly will make routine use of radioactive tracers when more cyclotrons are operating to prepare these materials. But the greatest potentialities lie in the direction of the release and control of the energy locked up within the atom. Dreams of such happenings as steamships crossing the oceans on a cupful of fuel, while still very far from realization, are becoming less visionary through the study of the inner structure of the atom—a study that depends on atomic projectiles of the highest velocity which can be produced only by the cyclotron.

LIST OF SYMBOLS

f = oscillator frequency—megacycles per second
e = electric charge on accelerated particle—electrons
H = magnetic field strength—kilo-oersteds
M = mass of accelerated particle—mass of proton = 1
R = maximum accelerating radius—inches
W = maximum energy of beam—million electron-volts
V = accelerating voltage (peak voltage between accelerating electrodes)—volts

History of Electrical Resonance

Our earliest knowledge of electricity was of the static kind; later came the voltaic cell and direct current. But not until the discovery of alternating or oscillating currents could the phenomenon of electrical resonance make its appearance. Today, as we turn the dials of our radio receivers and "tune in" on the station we want it is recognized how widespread the application of electrical resonance has become. Nevertheless, it seems that few have given thought as to how this important principle came to light and how and when it came into common use.

In an article "The History of Electrical Resonance" published in the October 1941 issue of the *Bell System Technical Journal* (pages 415–33), Julian Blanchard of the technical consulting staff, Bell Telephone Laboratories, New York, N. Y., reviews the early history of the phenomenon. He shows how electrical resonance had its roots in certain experiments with the Leyden jar; how the results of experiments were clarified by mathematical analysis and a correct theory formulated; and then, as the need and opportunity arose, how the principle was applied by inventive minds. "It hardly seems necessary," says the author, "to pursue the subject further than this point, considering how it so quickly thereafter became a commonplace item in our electrical storehouse."

The article includes a list of 32 references to early writings on the subject, which includes several papers by AIEE Past President M. I. Pupin.

Wind Shielding of Parallel Conductors

G. D. SHECKELS
ASSOCIATE AIEE

THE usual method of determining the wind loading of a conductor group is to multiply the wind load on a single conductor by the number of conductors on a crossarm. This does not take into account any possible shielding of the leeward conductors by the windward conductors. On straight lines, the only transverse load is the wind load; and if this wind load were actually less because of the shielding effect, the maximum design strength of the line could be reduced with a corresponding decrease in construction cost.

Experience and previous laboratory investigations have indicated the existence of wind-shielding effects in groups of parallel conductors of distribution lines, in which the leeward conductors are shielded by the windward conductors. This article reports the results of wind-tunnel tests to determine the magnitude of the factors controlling the wind-loading on groups of parallel conductors.

The existence of the wind-shielding effect has been indicated by experience with actual lines and by laboratory investigations. In several cases, lines have experienced wind velocities much greater than the maximum velocities for which they were designed. Yet the lines did not come down as expected, and the apparent additional strength could be explained only if some such element as wind shielding were involved.

The first laboratory investigations were concerned primarily with aeronautical work. In 1915, the British Advisory Committee for Aeronautics,[1] using a wind tunnel, measured the shielding effect of two one-half-inch diameter rods with spacings up to 6 diameters. A similar investigation with spacings up to 15 diameters was carried out in 1916 by T. Wong and T. Yu[2] at the Massachusetts Institute of Technology. Both of these investigations showed that there was a shielding effect in the range studied. In 1923, P. J. Howe[3] reported data collected on an outdoor model telegraph line. This investigation was limited to a standard one-eighth-inch conductor and $11^{3}/_{4}$-inch spacing as used on telegraph lines, but it showed clearly that shielding was present for that particular diameter and spacing. The National Electrical Safety Code,[4] in 1927, added the following to its rules for heavy and medium loading:

"... For supporting structures carrying more than ten wires not including cables supported by messengers, where the pin spacing does not exceed 15 inches, the transverse load shall be calculated on two thirds of the total number of wires with a miminum of ten wires."

Since power-distribution lines seldom have as many as ten conductors, this allowance, in general, is limited to communication lines. In 1936, the Edison Electric Institute[5] studied storm loading on an actual distribution line, and the shielding effect was one of the factors investigated. The EEI investigators suggested that wind shielding occurred only when a wind gust first struck the line, but they also stated that more data would be desirable before a definite conclusion is drawn. During the 1938 New England hurricane, the wind-shielding effect again was noticed, by the New England Power Association. At the suggestion of engineers of that company, the author selected the wind-shielding problem for a thesis subject at the Massachusetts Institute of Technology.

EXPERIMENTAL INVESTIGATION

For this investigation, a model distribution line was set up in the five-foot MIT wind tunnel. The model consisted of a group of $1^{1}/_{8}$-inch by $4^{1}/_{2}$-foot varnished wooden rods which simulated ice-coated conductors. All but one of the rods were supported in a sheet-metal angle frame as shown in Figure 1. One rod was supported independently of the frame, and all drag measurements were made on this rod. Different groupings were obtained by changing the positions of the rods in the

Figure 1. Model setup in wind tunnel; drag measurements made on left-hand rod

Paper presented at a meeting of the AIEE Seattle Section, December 1940, and subsequently awarded the AIEE District 9 prize for initial paper for that year.

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The author acknowledges the suggestions and guidance of Professor L. F. Woodruff and J. W. McBride of the Massachusetts Institute of Technology.

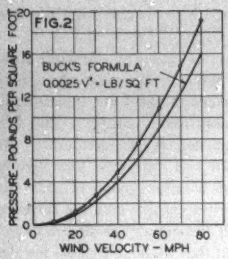
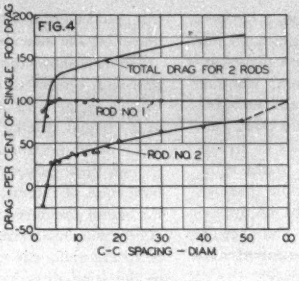
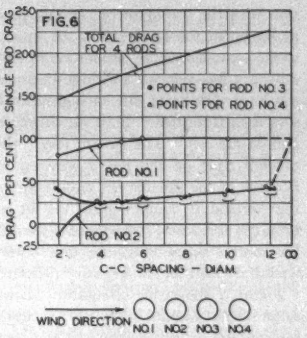


Figure 2. Effect of wind velocity on drag of single rod





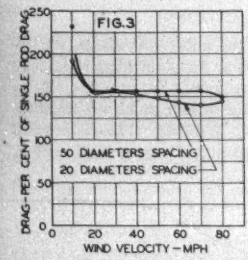
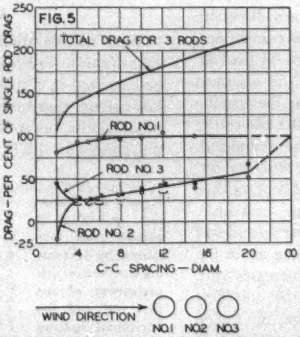


Figure 3. Effect of wind velocity on total drag of two rods



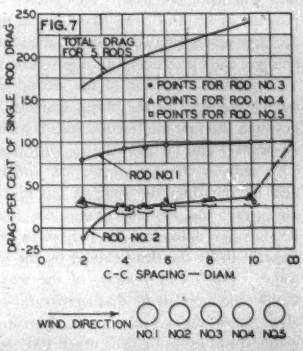


FIG.7
TOTAL DRAG FOR 5 RODS
• POINTS FOR ROD NO.3
△ POINTS FOR ROD NO.4
□ POINTS FOR ROD NO.5
ROD NO.1
ROD NO.2
DRAG - PER CENT OF SINGLE ROD DRAG
C-C SPACING - DIAM.
WIND DIRECTION
NO.1 NO.2 NO.3 NO.4 NO.5

Figures 4–7. Variation in individual drags of two, three, four, and five rods, obtained by increasing the horizontal spacing while maintaining the wind velocity constant at 60 miles per hour

frame with respect to the measured rod. All drag measurements were made with the standard wind-tunnel balances and drag systems, and the wind velocity was measured with a National Advisory Committee for Aeronautics micrometer manometer.

As a basis for comparison, measurements of drag versus wind velocity were made on a single rod as shown in Figure 2. The difference between H. V. Buck's curve and the experimental curve is probably due primarily to the fact that Buck's curve is based on stranded cable while a smooth rod was used for the experimental curve. In Figure 3, the effect of wind velocity on the shielding is shown for two rods at spacings of 20 and 50 diameters. Since the percentage drags were fairly constant over the greater portion of the curves, it was decided to run all the succeeding tests at a velocity of 60 miles per hour.

Figures 4, 5, 6, and 7 show the individual drag of each rod of the two-, three-, four- and five-rod groups. Several interesting points may be noticed from these curves. First, at spacings less than five or six diameters, the drag on the first rod is reduced by the presence of the rod or rods to the leeward of it. This reduction is probably caused by the slowing down of the air stream in front of the second rod.

Another point is that the slope of the drag curve for the second rod changes abruptly at spacings of about four or five diameters and the drag becomes negative at spacings less than three diameters. This is most easily explained by fluid-mechanics theory. When a fluid flows past a rod, eddies are formed on the downstream side of the rod. The eddies break off from alternate sides of the rod at a definite frequency and move downstream at a velocity less than that of the surrounding stream. This wake is termed a Kármán vortex trail and has been photographed at a Reynolds' number of 250.[6] This is relatively low when compared with the Reynolds' number of 54,000 obtained in the author's tests, but it is believed that the formation of the eddies is of the same general character in both cases. If a second rod is placed in the wake close to the first rod, the eddies produce circulation around the first rod as shown in Figure 9. This circulation acting in conjunc-

tion with the instantaneous stream produces a lift force as shown in the figure. On the upper right-hand side of the second rod, the circulation bucks the stream, producing a low-velocity and high-pressure area; while on the lower left-hand side, a high-velocity and low-pressure area is formed. Thus the lift force acts downward and to the left. The stream itself produces an instantaneous drag on the rod downward and to the right. Because of the greater net circulation at close spacings, the horizontal component of the lift might be greater than the horizontal component of the drag; and since the horizontal forces were the only ones measured, this would account for the negative measured drag.

Figure 9 shows the circulation about the second rod at an instant when a lower eddy is closer to the rod. An instant later an upper eddy will be closer and the circulation will have reversed. This causes the vertical components of lift and drag to act in an upward direction. As each succeeding eddy passes, the vertical components change, thus producing an alternating force on the rod. This vertical vibration of the second rod was observed during the tests at the closer spacings. As the spacing between the first and second rods is increased, the eddies are weaker and farther apart as they pass the second rod. This reduces the net circulation and the resulting lift, and by the time the spacing has reached four or five diameters, the net circulation has become negligible. Beyond five diameters the only force on the second rod appears to be the drag caused by the moving air in the wake. The mean velocity of the wake increases very slowly and even at 50 diameters out, it is still considerably below the velocity of the surrounding air. The velocity and resulting drag reach 100 per cent somewhere beyond 50 diameters.

Another point to be noticed in Figures 5, 6, and 7 is the behaviour of the third, fourth and fifth rods. When circulation occurs about the second rod, the uniformity of the wake is destroyed and considerable mixing takes place behind the second rod. High-velocity air is drawn in from the surrounding stream and the drags on the succeeding rods are higher because of the increase in mean velocity of the wake. As the spacing is increased, the net circulation about the second rod decreases. This also decreases the mixing which in turn lowers the mean wake velocity and the drag on the succeeding rods. By the time the spacing has reached five diameters, the net circulation has become negligible and the uniform wake acts on all the rods alike. From five diameters on out, the drags on the leeward rods are approximately the same and increase equally with an increase in spacing.

Referring again to Figures 4 to 7, the second, third, fourth, and fifth rods between four and ten diameters spacing appear to have approximately the same drag regardless of the number of rods in the group. On this premise, it might also be expected that the drag curves would coincide out beyond 10 diameters. The drags of third, fourth, and fifth rods at spacings up to 50 diameters could then be estimated by extrapolating the curves out along the second-rod curve of Figure 4.

Figure 8 shows the effect of changing the wind direction with respect to the plane of the rods. At a horizontal spacing of 12 diameters, the shielding is eliminated at a vertical spacing of only four diameters; and at a 52-diameter horizontal spacing, at five diameters. Although these curves are for two rods only, they give an indication of the effect on a larger group of rods. In the actual design of a distribution line with the shielding effect taken into account, it is essential that the conductors be strung uniformly so that they all lie in a plane parallel to the wind direction. Also, a strength reduction because of shielding should be used only where the line is erected on flat ground and where there is little chance for the wind to blow up under or down upon the line.

APPLICATIONS

With consideration of the above limitations, the results of this investigation show that a shielding effect may be expected in distribution lines. For example, take a low-voltage distribution line of four number-4 weatherproof conductors spaced at 30 inches. The diameter of the conductor itself is about 0.31 inch; and with a 0.50-inch coating of ice, the diameter is increased to 1.31 inches. The spacing is then 22.9 diameters. From Figure 6, extrapolating as mentioned before, the total wind load is (3) (55)+100=265 per cent of the single-conductor wind load. This would give a reduction of 33.8 per cent on the usual pole-strength requirements. In high-voltage transmission lines, the spacing is usually about 250 diameters so that the shielding effect is probably negligible.

As noted in the foregoing distribution-line example, the wind loads on the leeward conductors are 55 per

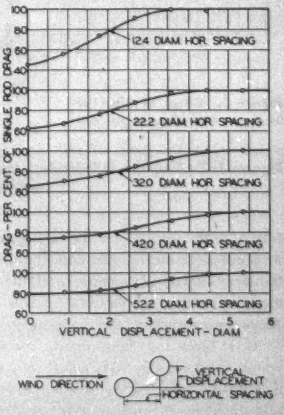


Figure 8. Variation in drag of second rod obtained by increasing the vertical displacement of the first rod and the horizontal spacing between rods, while maintaining the wind velocity constant at 60 miles per hour

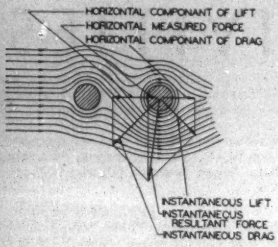


Figure 9. Forces on second rod caused by air flow about two rods at close horizontal spacings

cent of the single-conductor load. At 56.5 miles per hour, this would give an actual load of

$(0.55)\ (8) = 4.4$ pounds per square foot

or

$(4.4)\ (1.31/12) = 0.481$ pound per linear foot of conductor

The load on the windward wire would be

$(8)\ (1.31/12) = 0.874$ pound per linear foot

The weight of the conductor and its ice is

$0.128 + (0.31 + 0.5)\ (\pi)\ (0.5)\ (57.3)\ (1/144) = 0.634$ pound per foot

Then the resultant load for each shielded conductor is

$\sqrt{(0.481)^2 + (0.634)^2} = 0.80$ pound per foot

and for the unshielded conductor

$\sqrt{(0.874)^2 + (0.634)^2} = 1.07$ pounds per foot

Thus the shielding action gives a 25-per cent reduction in the resultant load on each leeward conductor. Since the conductor tension is proportional to the load for a constant sag, it follows that the leeward conductors could be designed with a 25-per cent reduction in maximum design tension. This would allow the use of conductors with less unit strength or with less cross-sectional area on the leeward side. Because it would be impossible to tell from which side the wind might come, it would be necessary to have both outside wires designed for full strength.

In actual practice, the wind is sometimes gusty at velocities as high as 60 miles per hour and the windward conductors might whip about and expose the leeward conductors. The whipping action depends on the weight of the conductor, the span length, and the general character of the wind in the particular locality. In some cases, the whipping might even nullify the shielding effect.

CONCLUSIONS

1. There is an appreciable shielding effect in the laboratory models of distribution lines.

2. At spacings of 20 diameters, the shielding increases slightly with an increase in velocity; but with 50 diameters spacing, the shielding stays fairly constant.

3. In the laboratory model, the shielding is eliminated at some spacing greater than 50 diameters.

4. In the laboratory model, the drag of the windward conductor is affected by the presence of a leeward conductor at spacings less than five diameters, and is not affected at spacings greater than five diameters.

5. The curves indicate that at any given spacing within the range of distribution line practice, the leeward conductors have approximately the same wind load regardless of the number of conductors or the relative position of the particular conductor, as long as the axes of the conductors lie in a plane parallel to the wind direction.

6. The angle between the wind direction and the plane through the axes of the conductors is a very important factor affecting the shielding. In practice, if the design strength of the line is to be reduced because of shielding, the conductors should all have the same sag and the terrain should be such that there would be little chance of the wind blowing up under or down upon the conductors.

7. Of interest to aeronautical engineers is the region between one and five diameters. This region merits further investigation both experimentally and mathematically.

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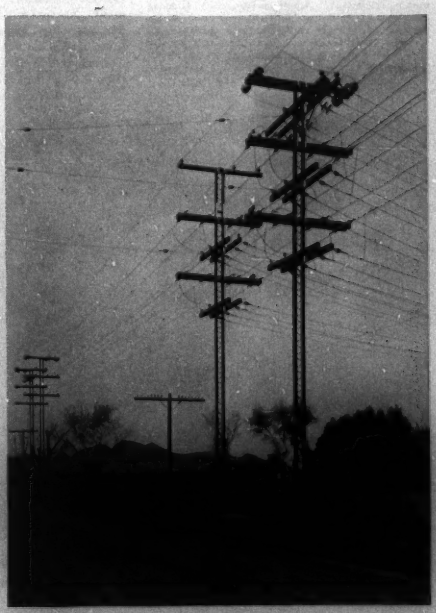


INSTITUTE ACTIVITIES

NATIONAL ....

Pacific Coast Convention to Be Held in Vancouver, B. C., September 9–11

Arrangements are being made for the Pacific Coast Convention which will be held in Vancouver, B. C., September 9–11, 1942. Convention headquarters will be in the Hotel Vancouver.

Since both Canada and the United States are concerned chiefly with the successful prosecution of the war, the local technical program committee has developed a program of a practical rather than a theoretical nature, directed along lines that will be helpful to members in their war effort. Tentative plans include four sessions on the subjects of system operation, apparatus, system planning, and industrial applications. In addition, there will be one or two student technical sessions, and there are prospects of a conference session.

The personnel of the 1942 Pacific Coast convention committee making the arrangements is:

H. J. MacLeod, *chairman;* C. A. Price and T. Ingledow, *vice-chairmen;* C. Arnott, *secretary;* F. V. Knight, *treasurer;* M. S. Barnes, F. J. Bartholomew, D. L. Brown, T. F. Hadwin, G. K. Haspel, K. L. Howe, A. C. Kelm, H. H. Krueger, G. L. Lane, F. C. Lindvall, F. W. MacNeill, G. F. Maughmer, C. J. Nevitt, E. W. Schilling, W. C. Smith, J. M. Somerville, J. H. Steede, J. A. Tames, A. L. Taylor, E. M. Wright.

Chairmen of the subcommittees are:

T. Ingledow, *entertainment;* W. D. Robertson, *registration and reception;* L. B. Stacey, *technical program;* A. Vilstrup, *finance;* T. H. Crosby, *golf;* T. C. Clarke, *transportation;* W. B. Coulthard, *student activities;* V. W. M. Fouracre, *publicity.*

Officers for 1942-43 Announced at Summer Convention

Officers of the Institute for the year beginning August 1, 1942, were announced in the report of the committee of tellers presented at the annual meeting, during the recently concluded summer convention at Chicago, Ill. The new officers are:

President: Harold S. Osborne, plant engineer, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y.

Vice-Presidents: K. B. McEachron, research engineer, General Electric Company, Schenectady, N. Y. (District 1, North Eastern); C. R. Jones, eastern transportation manager, Westinghouse Electric and Manufacturing Company, New York, N. Y. (District 3, New York City); A. G. Dewars, manager, system planning department, Northern States Power Company, Minneapolis, Minn. (District 5, Great Lakes); E. T. Mahood, engineer, Southwestern Bell Telephone Company, Kansas City, Mo. (District 7, South West); E. W. Schilling, professor and head of the department of electrical engineering, Montana State College, Bozeman (District 9, North West).

Directors: W. R. Smith, safety engineer, electric department, Public Service Electric and Gas Company, Newark, N. J.; K. L. Hansen, consulting electrical engineer, Harnischfeger Corporation, Milwaukee, Wis.; W. B. Morton, senior field engineer, Philadelphia Electric Company, Philadelphia, Pa. (re-elected).

National Treasurer: W. I. Slichter, professor emeritus of electrical engineering, Columbia University, New York, N. Y. (re-elected).

The board of directors for the administrative year beginning August 1, 1942, will consist of these newly elected officers; C. M. Laffoon, engineering manager, a-c generator engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., who was elected by the board at its meeting May 22, 1942, as a director to fill the unexpired term of R. E. Hellmund, deceased; and the following holdover officers:

D. C. Prince, Schenectady, N. Y. (*retiring president*); R. W. Sorensen, Pasadena, Calif. (*junior past president*); N. S. Hibshman, Bethlehem, Pa.; J. E. Housley, Alcoa, Tenn.; A. L. Jones, Denver, Colo.; C. A. Price, Hamilton, Ont.; W. R. Smith, San Francisco, Calif. (*vice-presidents*); T. F. Barton, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Washington, D. C.; L. R. Gamble, Spokane, Wash.; T. G. LeClair, Chicago, Ill.; F. R. Maxwell, Jr., Pensacola, Fla.; F. J. Meyer, Oklahoma City, Okla.; R. G. Warner, New Haven, Conn. (*directors*).

A detailed report of the 1942 summer convention is scheduled to appear in the August issue.

Steamer trips on Howe Sound, at Vancouver, B. C., are among the recreational attractions of the forthcoming AIEE Pacific Coast convention, to be held at Vancouver September 9–11, 1942

Board of Directors Meets

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., May 22, 1942.

Lieutenant General Andrew G. L. McNaughton was elected an Honorary Member of the Institute by unanimous vote of all present. (Affirmative ballots in writing from absent members of the board subsequently consummated the election, as required by the constitution. A biographical sketch of General McNaughton appears on page 363.)

Resolutions were adopted in memory of Past President Bion J. Arnold and Director R. E. Hellmund (published in June *Electrical Engineering*, pages 319 and 320).

C. M. Laffoon, East Pittsburgh, Pa., was elected a director of the Institute for the unexpired term, ending July 31, 1943, of R. E. Hellmund, deceased.

The annual report of the national treasurer for the fiscal year ending April 30, 1942, was presented and accepted.

The annual report of the board of directors for the fiscal year ending April 30, 1942, as prepared under the direction of the national secretary, was approved for presentation at the annual meeting of the Institute, on June 22, subject to any changes suggested by members of the board prior to the printing date (see pages 368–81).

The report of the committee on award of Institute prizes on the prizes awarded for papers presented in 1941 was presented (published on page 311 of the June issue of *Electrical Engineering*).

The board confirmed applications, upon recommendation of the committee on research, to The Engineering Foundation for continued support for the year beginning October 1, 1942, of the following research projects sponsored by AIEE: Project 74, Insulating Oils and Cable Saturants; Project 62, Welding Research Committee (sponsored jointly by AIEE and the American Welding Society).

Authorization was given for reimbursement to the Engineers Defense Board of the Institute's share, $110, toward out-of-pocket travel expense incurred in connection with the preparation, for the War Production Board, of a report on copper production.

Upon invitation of the Utah Section and recommendation of the District officers concerned, the board approved Salt Lake City, Utah, as the location for the Pacific Coast convention previously authorized to be held about September 1, 1943.

The following statement of scope of activity of the recently established technical committee on applications of electricity to therapeutics was approved:

"Treatment of all matter in which the dominant factors are the application of electric power to sanitation equipment, such as air-cleaning and sterilizing devices, and to the promotion of health and the analysis and treatment of disease or defects of the human body, such as X-ray equipment, diathermic equipment, cardiographs; investigations not directly applying to the human body but relating to health, and electric devices suitable for such purposes; the study of harmful effects of electric currents and radiations of electric devices upon the human body and means for the prevention of such effects, etc., are properly within the scope of this committee.

"Where certain devices are suitable for both therapeutic and industrial purposes, such as some X-ray equipment, or for therapeutic and other scientific investigations, or for sanitation and air-conditioning of domestic and commercial premises, action shall be joint with the committee on industrial power applications, the committee on basic sciences, or the committee on domestic and commercial applications, respectively; also, when appropriate, with the committee on safety."

Approval was given to the following appointments of AIEE representatives recommended by the standards committee:

Frederick G. Willis, on the Committee on Recording and Reproducing Apparatus being organized by the National Association of Broadcasters;

L. C. Ilsley, reappointment on the Mining Standardization Correlating Committee for the two-year term beginning January 1, 1942;

C. F. Dalziel, on the proposed Sectional Committee on Electric Fences.

Upon recommendation of the standards committee, the board approved a revision, submitted by the Underwriters' Laboratories under American Standards Association proprietary procedure, of American Standard C65, "Power Operated Receiving Appliances," and a revision, presented by the committee on instruments and measurements, of AIEE Standard No. 4, "Measurement of Test Voltages in Dielectric Tests."

In accordance with section 33 of the constitution, the following members of the committee of tellers were approved for appointment by the president:

R. B. Morton, *chairman*, G. C. Barney, M. L. Gardner, E. Joel, Jr., Charles W. Miller, J. F. Moore, N. S. Spatz.

Representatives appointed were:

H. B. Gear to Marston Medal Board of Award, to fill unexpired term, ending August 1, 1944, of Bion J. Arnold, deceased;

L. R. Mapes to Washington Award Commission, for two-year term beginning June 1, 1942, succeeding L. W. W. Morrow, whose term expires at that time.

H. H. Henline was reappointed national secretary of the Institute for the administrative year beginning August 1, 1942, in accordance with section 37 of the constitution.

As a result of a recommendation of the committee on professional training of the Engineers' Council for Professional Development that copies of society publications be sent to libraries of the armed forces of the country, where they can be made available to engineers in the service, the board of directors directed that a notice be published in the July issue of *Electrical Engineering*, inviting Institute members to donate their copies of *Electrical Engineering* for this purpose each month, after they have finished with them, a forwarding address to be furnished to each member volunteering.

Upon recommendation of the joint conference committee of presidents and secretaries of the Founder Societies, the board voted to invite the American Institute of Chemical Engineers to become one of the societies participating in the joint conference committee.

In acceptance of an invitation to the dedication of the Northwestern Technological Institute, at Evanston, Ill., on June 15–16, 1942, T. G. LeClair was appointed by the president, upon authorization by the board, to represent the Institute on this occasion.

Other actions taken included the following:

Minutes of the board of directors' meeting held January 29, 1942, were approved.

Actions of the executive committee on applications were reported and confirmed, as follows: As of March 23, 1942—9 applicants transferred and one elected to the grade of Fellow, 41 applicants elected and 30 transferred to the grade of Member, 182 applicants elected to the grade of Associate, 159 Students enrolled; as of April 10, 1942—3 applicants transferred to the grade of Fellow, 16 applicants transferred to the grade of Member, 508 elected to the grade of Associate, 85 Students enrolled.

Reports were presented and approved of meetings of the board of examiners held February 19, March 19, April 23, and May 21, 1942. Upon recommendation of that board, the following actions were taken: 3 applicants transferred to the grade of Fellow, 14 applicants transferred and 34 elected to the grade of Member, 517 applicants elected to the grade of Associate and one Associate reinstated, 265 Students enrolled.

Monthly disbursements were reported by the finance committee and approved by the board, as follows: $27,196.93 in February, $28,400.41 in March, $35,883.25 in April, and $31,654.16 in May. It was reported that the accounts of the Institute for the fiscal year which ended April 30, 1942, had been audited and the auditors' report was included in the annual report of the board of directors (pages 379–81).

Those present were:

President—David C. Prince, Schenectady, N. Y. *Past Presidents*—F. Malcolm Farmer, New York, N. Y.;

Send EE to the Army!

Institute members may do a service to engineers in the Armed Forces by sending their copies of *Electrical Engineering* to Army and Navy libraries after reading them. For the benefit of technical men in military and naval service, the committee on professional training of the Engineers' Council for Professional Development has suggested to its constituent engineering societies that arrangements be made to place current copies of the engineering journals in all organized libraries serving Army camps and ship and shore stations of the Navy serving technical contingents. Relevant to this suggestion, the Institute's board of directors took action at its May meeting inviting interested AIEE members to participate in the plan, and authorized a procedure to facilitate such participation. Any member who wishes to pass on his copy of *Electrical Engineering* each month should notify National Secretary Henline, who will supply the address of an authorized Army or Navy library serving engineering units of the Armed Forces. Members thus may forward their copies of the magazine with the assurance that they will be helping electrical engineers in the services to keep in touch with developments in the profession.

Future AIEE Meetings

Pacific Coast Convention
Vancouver, B. C., September 9–11, 1942

Winter Convention
New York, N. Y., January 25–29, 1943

R. W. Sorensen, Pasadena, Calif. *Vice-Presidents*—J. L. Hamilton, St. Louis, Mo.; N. S. Hibshman, Bethlehem, Pa.; J. Elmer Housley, Alcoa, Tenn.; Everett S. Lee, Schenectady, N. Y.; C. A. Price, Hamilton, Ont.; A. LeRoy Taylor, Salt Lake City, Utah. *Directors*—T. F. Barton and H. S. Osborne, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Washington, D. C.; Lester R. Gamble, Spokane, Wash.; T. G. LeClair and L. R. Mapes, Chicago, Ill.; W. B. Morton, Philadelphia, Pa.; R. G. Warner, New Haven, Conn. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

Contents of June 1942 Supplement

Supplementing the technical papers that have been preprinted from the 1942 volume of AIEE *Transactions* in the monthly *Transactions* sections of *Electrical Engineering* for January through June, a June 1942 "Supplement to *Electrical Engineering*—*Transactions* Section" is being issued. This supplement will contain five technical papers and all discussions of these papers and of those preprinted in the January–June monthly sections. Its publication completes the preprinting of papers and discussions presented at the 1942 winter convention, which was begun in the January 1942 section, in accordance with the provisions of the publication policy adopted at the AIEE summer convention in 1940. The June 1942 supplement will contain a total of 136 pages.

Copies of the supplement will be mailed shortly to those who entered advance orders. Others may obtain copies at 50 cents each ($1 outside United States and its possessions) from the AIEE order department, 33 West 39th Street, New York, N. Y., as long as the limited supply lasts.

Abstracts of three of the papers in the current supplement have already been published in *Electrical Engineering* in advance of the winter convention, in accordance with publication-policy provisions. Abstracts of the two remaining papers follow.

42-46—The Magnetic-Drag Tachometer; *R. G. Ballard.* This paper discusses a magnetic-drag tachometer equipment designed principally for aircraft use. The principle of operation makes possible an indicator which may be read very accurately under extreme conditions of aircraft use and at the same time may be easily adjusted and maintained. Because of the extreme reading accuracy obtainable, low inherent temperature errors and good compensation are essential. A method of obtaining these features is presented.

42-47—The Application of Voltage Regulators to Aircraft Generators; *L. W. Thompson* (*A '39*) *and F. E. Crever* (*A '27*). The use of high-capacity d-c generators on aircraft has required the development of regulators of rapid response, high accuracy, and with features for parallel operation of variable-speed machines. The fundamental requirements of light weight, ability to withstand shock and vibration and to give low radio interference were vital factors considered in the development. A device incorporating these features is described and analyzed. Results of tests on these equipments have shown that regulators with these features are vital to the operation of the electric loads of modern planes, both the military and commercial types. The tests show that the requirements have been met with devices suited to high production methods.

The other papers appearing in the supplement are:

42-22—Impulse and 60-Cycle Characteristics of Driven Grounds—II; *P. L. Bellaschi* (*F '40*), *R. E. Armington* (*Enrolled Student*), *A. E. Snowden* (*Enrolled Student*). Abstracted in December 1941 issue, page 600.

42-36—Synthetic or Equivalent Load Curves; *R. E. Hamilton* (*M '18*). Abstracted in January 1942 issue, page 45.

42-36—Acoustics and the Quiet Train Ride; *William A. Jack.* Abstracted in January 1942 issue, page 44.

Additions to List of Members for Life

Membership for life is granted by the AIEE to members who either have paid annual dues for 35 years, or have reached the age of 70 and have paid dues for 30 years. A list of those who have become members for life during the preceding year is published annually in *Electrical Engineering*. The following are the Institute members who have reached member-for-life status since publication of the last previous list in the July 1941 issue.

E. M. Ashworth
C. D. Backus
H. P. Baker
W. E. Barrows
W. B. Beals
R. Beeuwkes
G. R. Benjamin
A. Berggren
A. R. Bingham
W. T. Bivins
M. O. Bolser
H. L. Bostater
B. J. Bowen
F. E. Bullock
J. L. Burnham
L. H. Burnham
H. L. Caldwell
G. H. Calkins
E. A. Champlin
E. J. Cheney
H. C. Clement
E. H. Colpitts
D. O. Conkling
N. J. Conrad
M. T. Crawford
W. B. Creagmile
M. Creese
S. R. Crosse
J. H. Cunningham
N. H. Daniels
R. S. Danieh
J. C. Davenport
J. C. Davidson
G. Deakin
R. H. Dearborn
C. W. De Forest
A. P. Denton
H. Dingle
D. DuBois
R. W. Eaton
W. H. Evans
D. V. Fennessy
F. C. Finkle
A. C. Finney
D. J. Fleming
H. S. Foley
J. T. Frankenberg
M. Freund
A. J. Fry
N. E. Funk
H. R. Gabay
H. C. Gardett
H. D. Garretson
S. E. Gates
F. W. Gay
J. M. Gaylord
W. S. Gorsuch
S. Haar
A. W. Henshaw
A. S. Hill
A. J. Hixson
W. M. Hoen
W. A. Holland, Jr.
H. L. Hope
R. D. Hope
J. H. Hunt
S. E. Hutton
W. F. Hynes
A. G. Jones
A. S. Kappella
H. A. Kidder
M. King
A. J. Kohler
W. B. Kouwenhoven
J. C. Langdell
J. F. Lewis
E. A. Lof
K. H. Logan
W. V. Lyon
W. S. Maddocks
F. V. Magalhaes
L. A. Magraw
D. M. Mahood
F. I. Manvel
E. J. K. Mason
F. P. McBerty
F. P. McDermott
W. A. Miller
T. O. Moloney
G. H. Moore
F. D. Morgans
F. H. Murphy
P. J. Murphy
C. P. Nachod
F. D. Newbury
L. L. Newman
F. D. Nims
S. I. Oesterreicher
H. W. Osgood
R. D. Parker
F. J. Peturs
G. W. Pierce
C. W. Place
A. W. Post
P. H. Powell
M. W. Pullen
J. R. Read
A. B. Reynders
G. I. Rhodes
J. S. Riddile
J. H. Roddey
W. S. Rodman
G. S. Rose
H. S. Rush
L. K. Sager
C. H. Sanderson
J. F. Santa Cecilia
E. B. Schattner
A. Shane
V. W. Shear
F. H. Shepard
R. W. Shoemaker
A. E. Silver
W. M. Skiff
J. H. Smeaton
G. W. Smith
R. W. Smith
W. C. Smith
C. A. Soans
H. A. Stanley
H. W. Starr
L. A. Stenger
M. B. Stewart
A. Still
C. H. Taylor
W. B. Taylor
F. D. Thompson
C. E. Vance
H. B. Vincent
C. O. Von Dannenberg
A. H. Vorum
W. C. Wagner
L. D. Waldron
P. J. Walton
T. D. Waring
G. Y. Watt
J. W. Welsh
P. A. Westburg
W. C. Whitton
M. A. Whiting
V. Wichum
P. F. Williams
S. B. Williams
E. Woodbury
J. B. Woodyatt
W. R. Work
A. G. Wylie
F. E. Wynne
C. W. Young
H. B. Zimmerman

DISTRICT • • • • •

Nine Districts Announce Prize Awards for Papers

District prizes for AIEE papers have been announced by nine Districts. The awards are for papers presented during 1941, except Branch papers, which were presented during the academic year ending June 30, 1941.

District 1

Prizes for best paper and initial paper were awarded to T. A. Rich (A'41) for his paper, "Ampere-Squared-Second Recorder," presented at the North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941.

District 2

Prize for best paper was awarded to E. W. Boehne (M'37) for his paper, "The Geometry of Arc Interruption," presented at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941.

Prize for initial paper was awarded to J. D. McCrumm (A'36) for his paper, "An Experimental Investigation of Subharmonic Currents," presented at the same convention.

District 3

Prize for Branch paper was awarded to A. J. Dolan (A'42) for his paper, "The Design and Construction of a Vacuum-Tube Voltmeter for Educational Use," presented at the 15th annual Student Branch convention, Rutgers University, New Brunswick, N. J., April 24, 1941. Honorable mention for Branch paper was given to V. Petrucelly, Jr., for his paper, "An Automatic Intercommunicating System," presented at the same convention.

District 5

Prize for Branch paper was awarded to C. T. Damaske for his paper, "An Analysis of Color and Contrast of Automobile License Plates and Highway Signs," presented at a meeting of the University of Illinois Branch, Urbana, May 1941.

District 6

Prize for Branch paper was awarded to F. H. Slaymaker (A'42) for his paper, "Frequency Response and Efficiency Measurements of a Loud-Speaker," presented at the 14th annual District conference on student activities, Denver, Colorado, April 18–19, 1941.

District 7

Prize for Branch paper was awarded to L. K. Davis

(Enrolled Student) and B. W. Pike (Enrolled Student) for their paper, "Localized Annealing of Rock-Bit Bodies by Sixty-Cycle Induction Heating," presented at the South West District Student Branch convention, University of Missouri, Columbia, April 28–29, 1941.

District 8

Prize for Branch paper was awarded to R. E. Hedges for his paper, "An Electrical Method for Automatic Musical Transposition," presented at a joint meeting of the Los Angeles Section and the University of Southern California Branch, April 8, 1941.

District 9

Prize for Branch paper was awarded to R. W. Retherford for his paper, "The Design and Construction of the Longest Power Span in the Northwest," presented at a joint meeting at the Spokane Section and the University of Idaho Branch, Moscow, Idaho, May 9, 1941.

District 10

Prize for best paper was awarded to A. H. Frampton (M'38) and E. M. Wood (M'25) for their paper "The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario," presented at the AIEE summer convention, Toronto, Ont., June 16–20, 1941.

Prize for initial paper was awarded to H. M. Shockley (A'25) for his paper, "The Selection of Switchgear for Industrial Plants," presented at the Toronto Section meeting, October 24, 1941.

Prize for Branch paper was awarded to C. R. Hoar, H. G. Mah (A'41), and A. M. McQuarrie (A'41) for their paper, "The Predetermination of the Regulation of Salient-Pole Alternators," presented at a meeting of the University of Alberta Branch, Edmonton, November 19, 1940.

BRANCH • • • • • •

Annual Student Conference Held by North Central District

The 15th annual student conference of the AIEE North Central District (6) was held at Colorado State College of Agriculture and Mechanical Arts, Fort Collins, Colo., on April 17–18, 1942. Nine colleges and universities were represented at the conference, which had a registration of 134 students, faculty members, and guests. The program included two technical sessions; a luncheon; a meeting of incoming Branch chairmen, which was addressed by H. W. Bibber (A'21, M'30) chairman of the national committee on Student Branches, and professor of electrical engineering and head of the division of engineering, Union College, Schenectady, N. Y.; a meeting of Branch counselors; a banquet at which Professor Bibber spoke; and a final session at which President D. C. Prince was the speaker and at which awards for student papers were announced.

At the meeting of the Student Branch counselors it was voted to hold the 1943 student conference at the South Dakota State School of Mines, Rapid City, on April 23–24, 1943. Professor E. E. Clark (A'19, M'31) acting head of the electrical engineering department at South Dakota State School of Mines, was appointed chairman of the District committee on student activities and counselor delegate to represent the North Central District at the 1942 summer convention.

At the technical sessions the following student papers were presented:

PARALLEL OPERATION OF D-C SHUNT MOTORS, **James Bittner, Jack Miller, William Graham,** Colorado State College.

NOMOGRAMS, **Milton Crothers,** South Dakota State College.

ANTENNAS FOR PORTABLE OPERATION, **Sam C. Phillips,** University of Wyoming.

IMPULSE VOLTAGE TESTING, **Victor Miller,** University of Colorado.

THE FEASIBILITY OF ELECTRIC BRAKES FOR AUTOMOBILES, **Eugene H. Bender,** South Dakota School of Mines.

THE OPERATION OF THREE-PHASE MOTORS FROM A SINGLE-PHASE SUPPLY, **Edward Edison,** University of North Dakota.

THE ESSENTIALS OF DEMAND AND DEMAND METERING, **James Hollon,** University of Denver.

A DEMONSTRATION OSCILLOGRAPH, **Virgil Matheson,** University of North Dakota.

The District prize for a Branch paper was awarded to Edward Edison. Virgil Matheson received first honorable mention and Victor Miller, second honorable mention.

Student Conference Held By Great Lakes District

A conference of Student Branches in the Great Lakes District (5) was held on May 2, 1942, at Northwestern University Technological Institute, Evanston, Ill. In addition to the presentation of student papers, the program included a morning session, with E. W. Kimbark (M'35) acting head of the electrical engineering department of Northwestern Technological Institute, presiding, and Dean O. W. Eshbach and F. G. Seulberger, chairman of the department of industrial relations, speakers; a business meeting; a buffet luncheon; inspection of the laboratories of Northwestern Technological Institute; and a dinner meeting with the Chicago Section, at which President D. C. Prince was the principal speaker and K. V. Glentzer (A'36) chairman of the Chicago Section, toastmaster.

The following were among the student technical papers presented:

GRAPHICAL REPRODUCTION BY RADIO, **Herbert Sandstrom,** Michigan College of Mining and Technology.

A LABORATORY FOR THE CONSTRUCTION OF VACUUM TUBES, **George Gotschall,** University of Michigan.

ENGINEERING ASPECTS OF MASS SPECTROMETRY, **Joseph F. Hull,** University of Wisconsin.

HYSTERESIS LOOP TRACING BY MEANS OF THE CATHODE-RAY OSCILLOGRAPH, **R. R. Bush,** Michigan State College.

THE HISTORICAL, TECHNICAL, AND ECONOMIC ASPECTS OF COMMUNICATION BY FREQUENCY MODULATION, **Donald A. Franke,** University of Minnesota.

DESIGN OF INVOLUTE REFLECTORS FOR FLUORESCENT LAMPS, **Joseph A. Kaelin,** University of Illinois.

TRANSFORMER SURGE VOLTAGES, **Messrs. Hart, Flengey, Ptak,** and **Rehak,** Illinois Institute of Technology.

THE DESIGN OF A FLUORESCENT STUDY LAMP, **Dwight James,** Iowa State College.

Members of the District committee on student activities for 1942–43 were elected at the conference, as follows:

Professor H. O. Werner, University of Detroit, chairman; Professor M. M. Cory, Michigan State College; Doctor E. W. Kimbark, Northwestern Technological Institute.

District 2 Branch Convention Held at Princeton

The annual Student Branch convention of the AIEE Middle Eastern District was held April 17, 1942, at Princeton University, Princeton, N. J. The attendance totaled 172, representing 11 colleges and universities. Inspection trips to the plant of the Walker Gordon Dairy Company and the observatory and physics department of Princeton University were features of the program. in addition to the presentation of student papers. Prizes for papers were awarded by a jury consisting of Doctor Ralph E. Beal, RCA Manufacturing Company; H. E. Farrer (A'21), AIEE headquarters; Doctor Morland King, head of the electrical-engineering department, Lafayette College. W. M. Harris, Haverford College, won first prize, a $25 War Bond; G. W. Schroeder, Princeton University, second prize, $5 worth of War Stamps. The program of student technical papers follows:

CONSOLE-TYPE STAGE SWITCHBOARD AT HAVERFORD, **William M. Harris,** Haverford College

THE MEASUREMENT OF RADIO-FREQUENCY POWER, **Werner Rueggeberg,** The Johns Hopkins University

CORRELATION OF THE EARTH'S MAGNETIC FIELD AND THE AURORA BOREALIS, **Henry Lawrence Abbott,** Lehigh University

ELECTRICAL INSTALLATIONS IN THE NEW WAR DEPARTMENT BUILDING, **Richard B. Schuls,** University of Pennsylvania

COOKING BY ELECTRICAL CONDUCTION, **George W. Schroeder,** Princeton University

EFFECT OF INITIAL CONDITIONS ON SUBHARMONIC OSCILLATIONS, **T. P. Evans, C. F. Spitzer,** Swarthmore College

ULTRASONIC VIBRATIONS, **F. E. Morgan,** Drexel Institute of Technology

News Bulletin to Be Issued for District 1 Branches

A news bulletin to be circulated among the Student Branches of the AIEE North Eastern District will be undertaken, as the result of a decision reached at the meeting of Branch chairmen held May 1, 1942, at Schenectady, N. Y., in connection with the student convention at the North Eastern District meeting. Charles L. Seeger, Cornell University Branch, and Gerald Jacobs, Rhode Island State College Branch, will be joint editors of the publication, the first issue of which is scheduled to appear in the fall of 1942. The various Student Branches in the District will be asked to furnish announcements of meetings and news items for inclusion in the bulletin.

SECTION • • • • •

Chicago Section Sponsors Student-Paper Contest

A technical-paper contest for electrical engineering students at Illinois Institute of Technology and Northwestern University

Technological Institute has been conducted annually for the past three years by the AIEE Chicago Section. The three best papers are selected for oral presentation, on which prizes are based. Judges of this year's presentation, which was held April 30, 1942, were AIEE Director T. G. LeClair (F'40) Commonwealth Edison Company; F. H. Hollister (M'30) Sargent and Lundy, Inc.; W. J. Lempke (M'36) American Telephone and Telegraph Company. The prize-winning papers were:

First prize—"Ultrahigh-Frequency Measurements," by David Ringwalt, Martell Tuntland (Enrolled Students), and Wallace Giedt, all of Northwestern University Technological Institute.

Second prize—"Three-Phase Transmission Line Constants," by Leland Olson, E. H. Schrot, G. W. Staats, H. H. Tom (Enrolled Students), and William Dres, all of Illinois Institute of Technology.

Third prize—"Transformer Inrush Current Phenomena," by R. J. Bonnack, R. K. Dean, R. A. Koehler, J. N. Kunst, and R. W. Wessel (Enrolled Students), all of Illinois Institute of Technology.

Springfield Section Holds Ladies' Night. At a joint meeting with the Engineering Society of Western Massachusetts on May 19, 1942, the Springfield Section held its second annual ladies' night at the Hotel Sheraton, Springfield, Mass., with an approximate attendance of 160 persons. Following a smorgasbord dinner, Charles A. Mitchell, superintendent of schools in Easthampton, Mass., and former principal of the American School in Tokyo, spoke on Japan.

Washington Section Holds Outing

The second annual outing of the AIEE Washington Section was held at Rock Creek Recreational Center, East Leland and Beach Drive, Chevy Chase, Md., on June 13, 1942. Following the afternoon entertainment, which included athletics and a bridge tournament, with prizes for all events, a buffet supper was served.

During the evening the following new Section officers were installed:

G. R. Wilhelm (A'29) general plant engineer, Chesapeake and Potomac Telephone Company, Washington, D. C., *chairman;* A. G. Ennis (M'38) assistant professor of electrical engineering, George Washington University, Washington, D. C., *vice-chairman;* F. S. Black (A'34) engineer, Potomac Electric Power Company, Washington, D. C., *secretary-treasurer;* and W. F. Dietz (A'28) assistant manager, Westinghouse Electric and Manufacturing Company, Washington, D. C., and W. A. Laning (M'38) assistant professor of electrical engineering, University of Maryland, College Park, *members of the executive committee.*

F. M. Defandorf (M'37) physicist, National Bureau of Standards, Washington, D. C., and retiring chairman of the Section, presented the new chairman with a gavel. Mark Eldredge (F'33) specialist consultant for the War Production Board, presented watch charms to the three previous chairmen in recognition of their services. The recipients were F. M. Defandorf; R. W. Prince (M'30) chief engineer, Chesapeake and Potomac Telephone Company; and J. E. O'Brien (M'39) former head of the special problems section, technical standards division, Rural Electrification Administration, now a captain in the United States Marine Corps. As funds become available, it is planned to extend the presentations to other former chairmen. Entertainment during the evening was provided by a quartet from the Potomac Electric Power Company and an amateur magician.

Informal Luncheons Prove Successful at San Francisco. Some 15 years or more ago a small group of members of the San Francisco Section established the practice of meeting informally and without prearrangement at the Engineers Club once a week for luncheon and an informal chat about items currently of interest. It was not long before the "AIEE Table" became a fixture and a tradition in the Engineers Club dining room every Tuesday noon; its popularity was infectious, and the average attendance has grown from the original half-dozen or so to a present average of 40 or 50. There is no program, and the formal arrangements are limited strictly to time, place, food, and sociability. Frequently a really hot impromptu debate develops, and many weighty matters are "settled."

San Francisco Section Holds Past Chairmen's Reunion

Eighteen out of a total of 26 living past chairmen of the San Francisco Section were present for the "Past Chairmen's Night" meeting of the Section March 27. The affair repeated the success that has attended such occasions in other Sections, and a strong sentiment was expressed for making it an annual event. Only three of the past chairmen currently residing within the San Francisco Section area were absent from the meeting. In honor of his position of seniority as the Section's oldest living past chairman (1910–11) S. J. Lisberger was acclaimed as toastmaster.

The roster of attending past chairmen of the Section reads as follows:

S. J. Lisberger (1910–11), J. P. Jollyman (1920–21), W. P. L'Hommedieu (1921–22), J. A. Koontz (1923–24), F. R. George (1924–25), R. C. Powell (1925–26), D. I. Cone (1926–27), B. D. Dexter (1928–29), L. F. Fuller (1929–30), E. A. Crellin (1931–32), E. F. Maryatt (1932–33), W. C. Smith (1933–34), A. M. Bohnert (1934–35), E. M. Wright (1935–36), H. S. Lane (1936–37), F. S. Benson (1938–39), C. A. Andrews (1939–40), C. V. Fowler (1940–41).

In addition to these, honorary recognition also was extended to A. G. Jones, who for 19 years (1910–29) served the Section as its secretary.

Other past chairmen of the Section include:

G. O. Squier* (1904–05), C. L. Cory* (1905–07), A. M. Hunt (1907–08), C. W. Burkett (1908–09), G. R. Murphy* (1909–10), S. B. Charters* (1911–12), H. W. Crozier* (1912–13), A. H. Griswold (1913–14), C. J. Wilson (1914–15), A. H. Babcock* (1915–16), J. E. Woodbridge* (1916–17), L. R. Jorgensen* (1917–18), J. C. Clark (1918–19), W. G. Vincent (1919–20), H. H. Henline (1922–23), W. L. Winter (1927–28), P. B. Garrett (1930–31), R. O. Brosemer (1937–38).

* Deceased.

ABSTRACTS • • •

TECHNICAL PAPERS reviewed in this section were presented at the AIEE summer convention, Chicago, Ill., June 22–26, 1942. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters.

Communication

42-132—Poles and Pole Treatment; *Reginald H. Colley. 20 cents.* This paper is a digest of some of the more important pole problems. Analyses of pole use are correlated with information on the natural supply of raw material in the forest. Recent data on the preservative treatment and on the breaking strength of southern pine poles are included. There are sections on preparing poles for treatment, on new preservatives, and on the relation of moisture content to electrical resistance. Stress is laid on the advantages of standard framing and treating practice and on the virtual necessity for a broader use of available pole species, particularly in sizes required for joint use in power and communication lines.

42-133—The Combination of Probability Curves in Engineering; *Roger I. Wilkinson (A'35). 30 cents.* The elementary principles are presented by which an engineer can determine the characteristics of the probability distribution resulting from the joint action of two or more primary variates. Discrete and continuous variates of both the mutually exclusive and independent types are considered. Their exact combination is studied, and approximate moment and other methods are given for obtaining solutions when less comprehensive results are needed. For the case of independent variates the common operations of addition, subtraction, multiplication, and division are covered in some detail. Several examples drawn from various phases of engineering illustrate the principles and the kind of results obtainable.

PERSONAL • • • •

Carthrae Merrette Laffoon (A'24, M'39) engineering manager, a-c generator engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., was elected a director of the Institute to fill the unexpired term, ending July 31, 1943, of R. E. Hellmund (F'13) who died on May 16, 1942 (*EE, June '42, pages 320, 329*). Mr. Laffoon was born at Coldwater, Kans., on August 14, 1888, and received from the University of Missouri the degrees of electrical engineer in 1914 and master of arts in 1915. During 1914–15 he was research assistant at the engineering experiment station at the University of Missouri, Columbia, and during 1915–16 he did construction engineering for Black and Veatch, consulting engineers, Kansas City, Mo. He has been with the Westing-

Karsh photo

C. M. Laffoon | A. G. L. McNaughton | Edith Clarke | S. B Crary | H. Hagenguth

house Electric and Manufacturing Company since 1916. He worked as a design engineer on frequency changers and turbine generators until 1925, when he became section engineer in charge of large-capacity turbine generators. From 1930 to 1937 he was section engineer in charge of turbine generators, water-wheel generators, frequency converters, and synchronous condensers. In 1937 he became engineering manager of the a-c generator engineering department. He has been a member of the AIEE committee on electrical machinery since 1934 (chairman 1938–40) and was a member of the technical program committee 1938–40. He is also a member of Sigma Xi and Tau Beta Pi.

Andrew George Latta McNaughton (A'11) lieutenant general and commander in chief, Canadian Active Service Force, recently was elected an Honorary Member of the Institute "in view of his unusual record as an engineer, administrator, research director, and soldier." He is on leave of absence from his post as president of the National Research Council, Ottawa, Ont. He was born on February 25, 1887, at Moosomin, Sask., and received from McGill University the degrees of bachelor of science in 1910, master of science in 1912, and an honorary degree of doctor of laws in 1920 as well as an honorary degree of doctor of civil law from Bishop's University in 1937. He was a member of the teaching staff of McGill University from 1912 to 1914, when he entered private engineering practice. He joined the militia in 1909 and by 1913 had risen to the rank of major, commanding the third (Montreal) field battery. He began active military service at the outbreak of World War I, and in 1916 was made a lieutenant colonel. In 1917 he was appointed counter battery staff officer and in 1918 became brigadier general. Upon his return to Canada in 1919, he was made a member of the committee for the reorganization of the Canadian military forces. He became director of military training in 1920 and deputy chief of the general staff in 1923. When the Imperial Defence College was instituted in 1927 he was selected as Canadian representative. When he returned to Canada, he was appointed district officer, commanding military district 11 (British Columbia) in 1928, and in 1929 became chief of the general staff, highest Canadian military post, and major general. In 1935 he became president of the National Research Council and in that position actively promoted the application of science to industry. He played a large part in the design of the high-voltage laboratories of the Research Council at Ottawa and collaborated in the development of the cathode-ray direction-finder. In 1939 he was appointed by the Canadian government as technical adviser to a delegation of Canadian manufacturers to Great Britain to investigate the possibilities of producing munitions in Canadian plants. In 1939 he became inspector general of the first Canadian division of the Canadian Active Service Force and in 1940 was appointed lieutenant general and placed in command of a British army corps which included Canadian forces in England. He served as adviser to the Canadian delegation at the conference for the limitation of armaments at Geneva, Switzerland, in 1932, and was a member of the committee of trans-Atlantic air service at the imperial economic conference, Ottawa, in 1932. He was chairman of the interdepartmental committee on the trans-Canada airway, 1933–35, and since 1933 has been chairman of the National Research Council Associate committee on survey research. He is also a member of the Institution of Electrical Engineers (England) and the Engineering Institute of Canada. He is the author of a number of technical articles.

Edith Clarke (A'23, M'33) central-station department, General Electric Company, Schenectady, N. Y., co-author with S. B. Crary (A'31, M'37) of the paper, "Stability Limitations of Long-Distance A-C Power-Transmission Systems," has received the 1941 AIEE national prize award for best paper in engineering practice. She was born February 10, 1888, in Howard County, Md., and received the degree of bachelor of arts from Vassar College in 1908 and that of master of science in electrical engineering from Massachusetts Institute of Technology in 1919. After four years spent in teaching and study, she became computer for the research engineer of the American Telephone and Telegraph Company, New York, N. Y., in 1912 and from 1915 to 1919 was in charge of transmission calculations. In 1919 she joined the General Electric Company, Schenectady, N. Y., and was placed in charge of calculations. During 1921–22 she was professor of physics at Constantinople Women's College, Turkey (now Istanbul College). In 1922 she returned to the General Electric Company to work on power-generation and transmission problems in the central-station department. In 1930 she was placed in charge of a group of engineers working on generation and transmission problems. She was awarded the AIEE 1932 North Eastern District prize for best paper. She is also a member of Phi Beta Kappa. She holds patents on calculating and electrical power transmission devices and is the author or co-author of a number of technical articles.

S. B. Crary (A'31, M'37) central-station engineering department, General Electric Company, Schenectady, N. Y., co-author with Edith Clarke (A'32, M'33) of the paper, "Stability Limitations of Long-Distance A-C Power-Transmission Systems," has received the 1941 AIEE national prize award for best paper in engineering practice. He was born on May 17, 1905, at Marquette, Mich., and received the degree of bachelor of science from Michigan State College in 1927. From 1925 to 1927 he was engaged in work on plant records and tests with the City of Lansing (Mich.) Board of Water and Electric Light and Power Commission. In 1927 he joined the test course of the General Electric Company, Schenectady, N. Y., and in 1928 he was transferred to the transformer engineering department at Fort Wayne, Ind. In 1929 he returned to enter the company's central-station department. As co-author of a paper with M. L. Waring (A'29, M'36) he received the AIEE 1932 North Eastern District prize for initial paper, and as co-author with D. R. Shoults (A'35) he received honorable mention in the 1936 AIEE national prize award for best paper in theory and research.

J. H. Hagenguth (A'28) electrical engineer, high-voltage engineering laboratory, General Electric Company, Pittsfield, Mass., has received the 1941 AIEE national prize award for best paper in theory and research for his paper, "Volt-Time Areas of Impulse Spark-Over." He was born December 23,

1901, at Greipwald, Germany, and was graduated in 1925 as diplomingenieur from the Technische Hochschule, Munich, Germany. After a year spent in conducting a power survey with the Kraftwerke Westsachsen, he entered the transformer testing department of the General Electric Company, Pittsfield, Mass., in 1926. From 1927 to 1933 he was in the power transformer engineering department and in 1933 joined the staff of the high-voltage engineering laboratory of which he was later placed in charge. He received honorable mention in the 1937 AIEE national prize award for best paper in theory and research.

M. J. DeLerno (Enrolled Student) coauthor with R. T. Basnett (A'42) of the paper "An Electronic Circuit for Determining Power-Angle Oscillations," has received the 1941 AIEE national prize award for Branch paper. He was born at New Orleans, La., on January 8, 1922, and was graduated in 1941 with the degree of bachelor of engineering in electrical engineering from Tulane University of Louisiana, where he served as vice-chairman, 1939–40, and secretary treasurer of the AIEE Student Branch, 1940–41. In 1941 he entered the General Electric test course. Since September 1941 he has been studying for the degree of master of electrical engineering at Rensselaer Polytechnic Institute and working at the General Electric Company, Schenectady, N. Y., where he has been recently transferred to the industrial engineering department. He is also a member of Tau Beta Pi.

R. T. Basnett (A'42) control engineer, control engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., co-author with M. J. DeLerno (Enrolled Student) of the paper, "An Electronic Circuit for Determining Power-Angle Oscillations," has received the 1941 AIEE national prize award for Branch paper. He was born November 29, 1919, at Liverpool, England, and in 1941 was graduated with the degree of bachelor of engineering in electrical engineering from Tulane University of Louisiana. After a short time as student engineer at the Mansfield, Ohio, works of the Westinghouse Electric company, he was transferred to the company's East Pittsburgh plant as student engineer in the control engineering department. Recently he was appointed control engineer in that department.

G. A. Matthews (A'40) inspection and equipment engineer at the Detroit (Mich.) Edison Company, has received the 1941 AIEE national prize award for initial paper for his paper "Power Arc-Over on Overhead Distribution Lines and Newly Developed Equipment for Protection Against Conductor Burndown From That Cause." He was born at Clinton, Mass., on December 4, 1885. He was employed by the Connecticut Railway and Lighting Company from 1902 to 1914, when he joined the Western Local and Mining Company. He has been with the Detroit Edison Company continuously since 1916.

J. G. Trump (A'31) associate professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, coauthor with James Andrias (A'41) of the paper, "High-Voltage D-C Flashover of Solid Insulators in Compressed Nitrogen," has received honorable mention in the 1941 AIEE national prize award for best paper in theory and research. He received the degrees of electrical engineer from Brooklyn Polytechnic Institute in 1929, master of arts in physics from Columbia University in 1931, and bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1933. In 1929 he was employed by the General Electric Company, Pittsfield, Mass., as transformer designer and from 1929 to 1931 he was also instructor in electrical engineering at Brooklyn (N. Y.) Polytechnic Institute. Since 1940 he has been a member of the technical aid division of the national defense research committee. In 1941 he became an associate professor at Massachusetts Institute of Technology, where he has been engaged in research work and development of high-voltage electrostatic generators for the production of X rays and cathode rays for the medical use.

M. E. Strieby (M'22, F'41) transmission engineer, long lines department, American Telephone and Telegraph Company, New York, N. Y., co-author with J. F. Wentz (A'24) of the paper, "Television Transmission Over Wire Lines," has received honorable mention in the 1941 AIEE national prize award for best paper in engineering practice. He received the degrees of bachelor of arts from Colorado College in 1914, bachelor of science from Harvard University in 1916, and bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1916. He was employed by the engineering department of the New York Telephone Company 1916–17, and after a period of military service (1917–19) he entered the American Telephone and Telegraph Company as an engineer in the development and research department. From 1929 to 1940 he was transmission systems research engineer with the Bell Telephone Laboratories and in 1940 he joined the long lines department of the American Telephone and Telegraph Company.

J. F. Wentz (A'24) high-frequency transmission engineer, systems development department, Bell Telephone Laboratories, Inc., New York, N. Y., co-author with M. E. Strieby (M'22, F'41) of the paper "Television Transmission Over Wire Lines," has received honorable mention in the 1941 AIEE national prize award for best paper in engineering practice. He received the degrees of electrical engineer from Lehigh University in 1917 and master of arts from Columbia University in 1923. After an interval of military service (1917–19) he entered the engineering department of the Western Electric Company and in 1924 transferred to the research department of the Bell Telephone Laboratories. In 1930 he was placed in charge of coaxial cable design and in 1940 he was appointed high-frequency transmission engineer in charge of coaxial systems for telephone and television.

L. F. Kennedy (A'37, M'39) relay application engineer, General Electric Company, Schenectady, N. Y., co-author with A. T. Sinks (A'36) of the paper, "New Current Transformer for Bus Differential Protection," has received honorable mention in the 1941 AIEE national prize award for best paper in engineering practice. He was graduated from Rensselaer Polytechnic Institute with the degree of electrical engineer in 1922 and in that year joined the General Electric Company to do test work. He was transferred to the switchgear engineering department in 1923 and from 1928 to 1939 he was in charge of relay development. In 1939 he entered the central-station engineering department as application engineer.

A. T. Sinks (A'36) designing engineer, instrument transformer engineering department, General Electric Company, Lynn, Mass., co-author with L. F. Kennedy (A'37, M'39) of the paper "New Current Transformer for Bus Differential Protection," has received honorable mention in

M. J. DeLerno

R. T. Basnett

G. A. Matthews

the 1941 AIEE national prize award for best paper in engineering practice. He was graduated from Yale University in 1929 with the degree of bachelor of science in electrical engineering and in that year entered the test course of the General Electric Company. In 1930 he was assigned to work on instrument transformer design, and in 1935 was placed in charge of the design and development of dry-type instrument transformers at the company's plant in Lynn, Mass., where he has been continuously since that time.

James Andrias (A'41) assistant engineer, naval ordnance laboratory, United States Navy Yard, Washington, D. C., co-author with J. G. Trump (A'31) of the paper, "High-Voltage D-C Flashover of Solid Insulators in Compressed Nitrogen," has received honorable mention in the 1941 AIEE national prize award for best paper in theory and research. He received from Massachusetts Institute of Technology the degrees of bachelor of science in electrical engineering in 1939 and master of science in electrical engineering in 1940. In 1940 he entered Stone and Webster Engineering Corporation, Boston, Mass., as an electrical designer, and since 1940 he has been associated with the naval ordnance laboratory.

T. R. Tate (M'24, F'35) has resigned as director of the national defense power staff and chief of the bureau of electrical engineering, Federal Power Commission, Washington, D. C., to become consulting engineer with the firm of Charles T. Main, Inc., Boston, Mass., serving as the company's representative in Washington, D. C. He joined the Federal Power Commission in 1934 as director of the national power survey and from 1936 to 1938 was chief of the commission's division of power resources and requirements. In 1938 he became chief of the division of gas and electric resources. He was made chief of the division of electric resources and director of the national defense power staff in 1940.

J. V. Alfriend, Jr. (A'33, M'41) senior engineer, bureau of electrical engineering, Federal Power Commission, Washington, D. C., has become consultant on industrial and power problems related to plant locations with the National Resources Planning Board. He joined the Federal Power Commission in 1934 as associate engineer and later was made engineer. In that capacity he made surveys of power requirements for industrial establishments and during 1941 he was engaged in the analysis of the effect of the defense program on electric loads of major utility systems.

J. P. Clayton (F'36) chief system officer, Commonwealth Edison Company, Chicago Ill., recently received the honorary degree of doctor of engineering from Tulane University of Louisiana. He received the degree of bachelor of engineering from that institution in 1909 and that of mechanical engineer from the University of Illinois in 1911. He has been with the Commonwealth Edison Company since 1932.

OBITUARY • • • •

James Gilbert White (A'89, M'00) chairman, J. G. White and Company, New York, N. Y., died June 2, 1942. Born August 29, 1861, at Milroy, Pa., he received from Pennsylvania State College the degrees of bachelor of arts in 1882 and master of arts in 1884, and doctor of philosophy from Cornell University in 1885. He was instructor of physics at the University of Nebraska, Lincoln, from 1895 to 1887, when he established the Western Engineering Company at Lincoln, Nebr., and became its president. In 1890 he sold the Western Engineering Company to the Edison United Manufacturing Company and was employed by that company as general United States agent for street railway construction. In that year, after the formation of the Edison General Electric Company, he established a contract engineering business in New York, N. Y., under the firm name of J. G. White and Company and became its president. In 1900 he formed the J. G. White Company, Ltd., London, England; in 1905 the Canadian White Company, Ltd., Montreal, P. Q.; and in 1913 the J. G. White Engineering Corporation, New York, N. Y., as an affiliate of the J. G. White Company. He was also associated with several other engineering firms as president or director. As a contracting engineer, he was active in the design and installation of a number of electric railways, among them the Buffalo–Niagara Falls Electric Railway, as well as power plants, bridges, and buildings throughout the United States and foreign countries. He served as a vice-president of the Institute, 1907–09, and a manager, 1904–07, and was a member of the Edison Medal committee, 1909–14. He was also a member of the American Society of Civil Engineers.

L. A. S. Wood (M'24) chief lighting engineer, Westinghouse Electric and Manufacturing Company, Cleveland, Ohio, died on May 5, 1942. He was born on August 15, 1874, at London, England. After studying with a tutor until 1883, he attended City of London School and the University of London. In 1895 he joined the Edison and Swan United Electric Light Company, Ltd., London, England and from 1897 to 1901 he was manager of the company's London showrooms. From 1901 to 1903 he was manager of the London office of Gent and Company. He carried on an independent business, specializing in illumination, from 1903 to 1906, when he became special representative in Europe for the Union Electric Company, London, England. In 1911, he joined the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as an illumination specialist. From 1915 to 1920 he served as district sales manager for the George Cutter Company, South Bend, Ind., and when that company was absorbed by the Westinghouse company in 1920, he was appointed manager of the illuminating section. In 1930 he was transferred to Cleveland as sales manager, in 1935 was made chief lighting engineer of the lighting division with headquarters in New York, N. Y., and in 1936 returned to Cleveland in that capacity. He had an active part in laying out street lighting systems in a number of cities in the United States and Europe and served as a lighting consultant for the Chicago (Ill.) Exposition and the Great Lakes Exposition. He was a past president of the Illuminating Engineering Society.

William Edwin Freeman (A'11, M'27) professor of electrical engineering and assistant dean of engineering, University of Kentucky, Lexington, died May 21, 1942. He was born at Lexington, Ky., on September 25, 1880, and received from Transylvania College the degree of bachelor of arts in 1901, and from the University of Kentucky the degrees of bachelor of mechanical engineering in 1904 and electrical engineer in 1912. In 1904 he entered the engineering department of the Western Electric Company. In 1911 he was appointed head of the department of electrical engineering at the University of Kentucky. During 1920–21 he served as supervisor of commercial training with the Westinghouse Electric and Manufacturing Company, in 1921 returning to the University of Kentucky as head of the department of electrical engineering and acting dean of the college of engineering. In 1922 he was appointed assistant dean of the college of engineering, a position he held continuously since that time, except for a year (1934) as acting dean. He served as an AIEE vice-president, 1931–33, had been a member of the committee on Student Branches and the committee on education. He was counselor of the AIEE Student Branch at the University of Kentucky 1930–32 and 1935–36. He was also a member of the Society for the Promotion of Engineering Education, and Tau Beta Pi.

Daniel Edgar Manson (A'07, M'28) retired engineer, Boston, Mass., died on April 30, 1942. He was born at New Haven, Conn., on October 13, 1870 and was graduated from Yale University in 1892 with the degree of bachelor of arts. He was employed by the Thomson Houston Electric Company from 1892 to 1893, when he joined the Dennison Electrical Engineering Company, New Haven, Conn. He was secretary-treasurer of the Connecticut Electric Company, New Haven, Conn., from 1895 to 1897 and in that year was employed by the Westinghouse Electric and Manufacturing Company as salesman of electrical apparatus. From 1905 to 1909 he was manager of the company's Boston office. He was made vice-president of the Malden (Mass.) Electric Company, Malden and Melrose (Mass.) Gas Light Company,

Suburban Gas and Electric Company, Revere, Mass., Haverhill (Mass.) Electric Company, Fitchburg (Mass.) Gas and Electric Company, and Springfield (Mass.) Gas Light Company in 1909. In 1912 he became vice-president of the Charles H. Tenny and Company. He also served as president or vice-president of other utility companies in New Hampshire, New York, New Jersey, and Pennsylvania.

Eustace William Ackland (A'05, M'20) managing director, National Electrical and Engineering Company, Ltd., Wellington, New Zealand, died March 28, 1942. He was born at Christchurch, New Zealand, on October 10, 1874, and studied at the Technical College, Sydney, Australia. In 1890 he was employed by Woodhouse and Rawson, Sydney, to do electrical work and in 1894 he joined the Silvertown Telegraph Works Company, Ltd., as engineer in charge of electrical work. In 1899 he became engineer in charge of outside electrical contracts with Edge and Edge, Sydney, and after a year as acting electrical engineer with the Perth Electric Tramways, Ltd., returned to Edge and Edge in 1901 as engineer in charge of cable laying. He became electrical engineer with J. G. White and Company, Auckland, New Zealand, in 1902, in 1903 he was appointed power superintendent, Auckland Electric Tramways, and in 1904 was made assistant engineer with Noyes Brothers, at Dunedin, New Zealand. In 1906 he established the National Electrical and Engineering Company, Ltd., and became its managing director. Shortly after, he was appointed New Zealand agent for the General Electric Company and the British Thomson-Houston Company, Ltd.

Patrick Kelly (A'19) managing director, Edison Swan Electric Company, Ltd., London, England, died April 5, 1942. He was born June 25, 1888, at Ajmere, India, and attended Pratt Institute and St. Joseph's College. In 1907 he was employed by Marshall Sons and Company, Ltd., Bombay, India, and after a period with the Great Indian Peninsula Railway, he joined the F. C. Osler Company, Ltd., Bombay, India, in 1909 to work on light and power installations. From 1912 to 1914 he was engaged in hydroelectric installation for the Amir of Afghanistan, at Kabul, Afghanistan. After working for a short time on power-house construction for the General Electric Company, New Haven, Conn., he spent a year studying at Pratt Institute, Brooklyn, N. Y., 1914–15, returning to the General Electric Company in 1915 as a salesman, and remaining until 1919, except for an interval of military service. In 1920 he was employed by the British Thomson-Houston Company, Ltd., as manager of the Bombay office and in 1923 he joined the Schenectady office of the International General Electric Company. After serving in the London and Paris offices of that company, he was appointed head of merchandising sales, British Thomson-Houston Company, London, England. In 1928 he became managing director of the Edison Swan company.

William Hill Sasscer (A'28, M'40) electrical and mechanical department, Pennsylvania Coal Company, Scranton, died on April 28, 1942. He was born May 4, 1900, at Upper Marlboro, Md., and received the degree of bachelor of science in electrical engineering from Virginia Polytechnic Institute in 1922. In that year he joined the turbine drafting department of the General Electric Company, Schenectady, N. Y., in 1923 he was transferred to the testing department, and in 1924 he entered the industrial sales department. He did motor sales work with the General Electric Company in Philadelphia, Pa., from 1925 to 1927, when he joined the power department of the Philadelphia and Reading Coal and Iron Company, Pottsville, Pa. He was employed by the Pennsylvania Coal Company in 1929 to make a survey of d-c power systems in mines and the following year was transferred to the electrical and mechanical department.

Edward W. Kearns (A'24) central district manager, General Cable Corporation, Chicago, Ill., died on February 18, 1942. He was born on August 3, 1884. In 1899 he joined the Electric Supply Company, Chicago, Ill., and in 1901 he was employed by the Manhattan Electric Supply Company, Chicago, Ill. From 1903 to 1913 he was sales engineer for the Monarch Electric and Wire Company, Chicago, Ill., and from 1913 to 1918 he was sales manager. After service with the United States Army signal corps at Washington, D. C., he became district manager of the Habirshaw Electric Cable Company, New York, N. Y., with headquarters in Chicago, Ill. He was later central district manager for the Safety Cable Company, Chicago, Ill., and in 1930 he became central district manager for the General Cable Corporation.

Eugene William Sanderson (A'10) power plant engineer, New York Telephone Company, Brooklyn, died in March 1942. Born November 21, 1886, at Aurora, S. Dak., he received the degree of bachelor of science from South Dakota State College in 1906. He entered the test course of the General Electric Company, Schenectady, N. Y., in 1907 and in 1908 joined the company's testing department at Pittsfield, Mass., returning to the testing department at Schenectady the same year. After a short time with the Electrical Testing Laboratories, New York, N. Y., he joined the Western Electric Company in 1911. In 1913 he was employed by the New York Telephone Company and was engaged in power plant engineering until 1927, when he was appointed engineer in charge of power plants for the Long Island area.

John Palmer (A'13) district engineer, Canadian Westinghouse Company, Ltd., Montreal, P. Q., died April 20, 1942. Born June 20, 1881, at London, England, he received the degree of bachelor of science in electrical engineering from London University. He was employed as an engineering apprentice with Johnson and Phillips, electrical contractors, London, England, and as chief operator at the power plant of the Southampton (England) Corporation, before going to Canada in 1910. He joined the engineering department of the Canadian Westinghouse Company in 1911 and the following year was transferred to the service department. After two years as a construction engineer, he served until 1920 as the company's district engineer in Calgary, Alberta, except for an interval of military service. In 1920 he was appointed district engineer with headquarters in Montreal.

John W. Andree (M'26) production engineer, Southern California Edison Company, Ltd., Los Angeles, died on April 7, 1942. He was born November 1, 1879, at Cologne, Germany, and was graduated from the University of Illinois in 1907 with the degree of bachelor of science. During 1907 he did electrical construction work for the Bion J. Arnold Company, Chicago, Ill., and after a short time as substation operator with the Commonwealth Edison Company, Chicago, Ill., he taught engineering at DePaul University (1908–10), Chicago, Ill. In 1910 he joined the Southern California Edison Company as production engineer.

Charles William Townsend (A'41) assistant designer, engineering department, Central New York Power Corporation, Syracuse, N. Y., died on May 28, 1942. He was born July 29, 1907, at Waterville, N. Y., and received the degree of bachelor of science in electrical engineering from Clarkson College of Technology in 1932. In 1933 he became instructor of mathematics at the Rensselaer Falls (N. Y.) High School and in 1938 he joined the Central New York Power Corporation as draftsman. He was transferred to the engineering department in 1940.

James Andrews Atwood (A'16) electrical construction engineer, Dayton, Ohio, died January 7, 1942. He was born at Burlington, Vt., on June 17, 1882. From 1901 to 1906 he was employed in the testing department of the Hobart Electric and Manufacturing Company and after working with the Ditto American Fixture and Manufacturing Company, he became engineer and superintendent for the Charles I. Tyson Company, Dayton, Ohio. Since 1912 he had maintained an electrical contracting and consulting practice.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on June 18, 1942, recommended the following members for transfer to the grade of membership indicated. Any ob-

jections to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dibner, Bern, executive vice-president, Burndy Engineering Company Inc., New York, N. Y.
Holben, W. P., distribution engineer, Duquesne Light Company, Pittsburgh, Pa.
Jeffries, Zay, technical director, lamp department, General Electric Company, Cleveland, Ohio.
McPhail, H. F., assistant chief electrical engineer, United States Bureau of Reclamation, Denver, Colo.

4 to grade of Fellow

To Grade of Member

Birge, K. R., electrical engineer, City of Pasadena Municipal Light Department, Pasadena, Calif.
Bishop, G. E., electrical superintendent, Coast Counties Gas and Electric Company, Santa Cruz, Calif.
Burrell, R. W., assistant engineer, Consolidated Edison Company of New York, Inc., New York, N. Y.
Conklin, W. A., engineer, Commonwealth and Southern Corporation, Jackson, Mich.
Draper, L. L., protective relay designer, Bureau of Light and Power, Los Angeles, Calif.
Ettinger, V. P., transmission and protection engineer, Southwestern Bell Telephone Company, St. Louis, Mo.
Farnham, S. B., engineer, General Electric Company, Schenectady, N. Y.
Giddlund, H. F., electrical engineer, Public Service Company, Denver, Colo.
Harrison, W. P., assistant distribution engineer, Oklahoma Gas and Electric Company, Oklahoma City.
Hedrich, W. A., instructor in electrical engineering, Michigan State College, East Lansing.
Heffernan, F. J., electrical specifier, Otis Elevator Company, Yonkers, N. Y.
Hoard, R. L., professor of electrical engineering, University of Washington, Seattle.
Hood, H. T., commercial engineer, General Electric Company, Portland, Oreg.
Johnson, W. C., assistant professor of electrical engineering, Princeton University, Princeton, N. J.
Lamson, J. V., electrical engineer, Bonneville Power Administration, Portland, Oreg.
Lewis, M. G., electrical engineer, Austin Willmott Earl, consulting engineer, San Francisco, Calif.
Longley, F. R., electrical engineer, Western Massachusetts Companies, Springfield, Mass.
Mathewson, H. G., building and equipment engineer, Southwestern Bell Telephone Company, Dallas, Tex.
Matthews, G. A., equipment and inspection engineer, Detroit Edison Company, Detroit, Mich.
McKinley, W. W., electrical engineer, Commonwealth and Southern Corporation, Jackson, Mich.
McNeill, H. E., associate engineer, Bonneville Power Administration, Portland, Oreg.
Morgan, W. A., assistant engineer, United States Bureau of Reclamation, Denver, Colo.
Morris, W. D., associate professor of electrical engineering, Louisiana State University, Baton Rouge.
Pettibone, G. H., section head, General Electric Company, Schenectady, N. Y.
Pinchert, W. F., electrical engineer, Office of the United States District engineer, Fort Sam Houston, Tex.
Rehagen, E. S., application engineer, Westinghouse Electric and Manufacturing Company, St. Louis, Mo.
Roters, H. C., director of research, Fairchild Aviation Corporation, Jamaica, N. Y.
Samson, J. J., supervising electrical equipment engineer, Commonwealth Edison Company, Chicago, Ill.
Seaman, J. L., production, schedule, and office operation engineer, Commonwealth and Southern Corporation, Jackson, Mich.
Shaw, F. W., electrical engineer, Kansas City Power and Light Company, Kansas City, Mo.
Shoults, D. E., application engineer, General Electric Company, Schenectady, N. Y.
Sinks, A. T., designing engineer, General Electric Company, Lynn, Mass.
Soliday, J., electrical engineer, The Panama Canal, Diablo Heights, C. Z.
Spatz, N. S., engineer, Public Service Electric and Gas Company, Newark, N. J.
Staacke, H. F., general commercial superintendent, Houston Lighting and Power Company, Houston, Tex.
Steiner, J. G., engineer, Commonwealth and Southern Corporation, Jackson, Mich.
Treadway, W. H., engineer, Rural Electrification Administration, St. Louis, Mo.

37 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before July 31, 1942, or September 30, 1942, if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Blake, G. R., 8 Eddy Street, Waltham, Mass.
Jordan, J. F., General Electric Company, Schenectady, N. Y.
Murphy, T. H., American Locomotive Company, Schenectady, N. Y.
Palmer, H. L., General Electric Company, Schenectady, N. Y.
Saxon, C. B. (Member re-election), American Locomotive Company, Schenectady, N. Y.
Schutz, H. (Member), Thayer School of Engineering, Dartmouth College, Hanover, N. H.
Smith, G. J. (Associate re-election), Eastman Kodak Company, Rochester, N. Y.
Weed, L. J. (Member), Boston Edison Company, Boston, Mass.

2. Middle Eastern

Adams, W. R. F., General Cable Corporation, Washington, D. C.
Bockenek, D. M. (Associate re-election), War Department, Corps of Engineers, Washington, D. C.
Brady, P. B., United States Navy Yard, Philadelphia, Pa.
Daus, M. W. (Associate re-election), Reconstruction Finance Corporation, Washington, D. C.
Dignan, R. G., Cleveland Electric Illuminating Company, Cleveland, Ohio.
Eskin, H., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Ficchi, R. F., United States Navy Yard, Philadelphia, Pa.
Gordon, K. H. (Associate re-election), Pennsylvania Railroad, Philadelphia, Pa.
Hadley, J. L. (Member), Peerless Electric Company, Warren, Ohio.
Harlow, W. G., General Electric Company, Philadelphia, Pa.
Hatchwell, J. A., United States Navy Yard, Philadelphia, Pa.
Hengstler, J. J., War Department, Corps of Engineers, Washington, D. C.
Hunter, W. F., General Electric Company, Philadelphia, Pa.
Kelly, J. A., General Electric Company, Philadelphia, Pa.
Lawton, H. J., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Lilie, J. P., Cleveland Electric Illuminating Company, Cleveland, Ohio.
Morris, J. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Robinson, W. P., Jr., Whitman, Requardt and Smith, Edgewood Arsenal, Md.
Rustebakke, H. M., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Smith, W. L., New York Shipbuilding Corporation, Camden, N. J.
Steudel, E. M., Allied Chemical and Dye, Philadelphia, Pa.
Syracopoulos, P. C., Goodyear Tire and Rubber Company, Akron, Ohio.
Witsberger, C. J., Follansbee Steel Corporation, Follansbee, W. Va.

3. New York City

Boyer, K., Bell Telephone Laboratories, Inc., Whippany, N. J.
Brown, Q. T., Western Electric Company, Kearney, N. J.
Miller, O. G. (Associate re-election), Rome Cable Corp., New York, N. Y.
Quitter, J. P., Westinghouse Lamp Division, Bloomfield, N. J.
Reed, B. A., Jersey Central Power and Light Company, Asbury Park, N. J.
Romano, B. A., United States Army Signal Corps, c/o Postmaster, New York, N. Y.
Shackelford, B. E. (Member re-election), R C A, New York, N. Y.
Storms, C. F. (Member), E. B. Badger and Son Company, New York, N. Y.
Stevens, E. R., New York Transit Systems, New York, N. Y.
Sutton, W. J., Ford, Bacon and Davis, Inc., New York, N. Y.
Swendeman, H. A., Westinghouse Electric and Manufacturing Company, New York, N. Y.
Vart, A. J. (Associate re-election), Geo. G. Sharp, New York, N. Y.
Wilcox, D. R., Morganite Brush Company, Long Island City, N. Y.

4. Southern

Demetroulas, N. P., United States Army, Ft. Eustis, Va.
Herman, G. R. (Member), Chicago Bridge and Iron Company, Morgan City, La.
Hunter, J. B., Taylor Parker Company, Inc., Norfolk, Va.
Raine, R. W. (Associate re-election), Robert and Company, Jacksonville, Fla.
Sinclair, W. D. (Member), South Carolina Public Service Authority, Charleston, S. C.
Smoke, C. H. (Member), U. S. Engineer Office, Norfolk, Va.

5. Great Lakes

Applegate, E. G. (Member), Crane Company, Chicago, Ill.
Bastis, E. T., Federal Cartridge Corporation, New Brighton, Minn.
Brackney, H. W. (Member), General Electric X-Ray Corp., Chicago, Ill.
Crossett, G., A. O. Smith Corporation, Milwaukee, Wis.
McGee, H. S., Public Service Company of Northern Illinois, Maywood, Ill.
Mills, G. R., Union Electric Company of Illinois, Venice, Ill.
Misegades, E. L., General Electric Company, Fort Wayne, Ind.
Monthei, L. J., K. R. Brown, Consulting Engineer, Des Moines, Iowa.
Ordas, A. F., General Electric Company, Ft. Wayne, Indiana.
Rich, H. S., Milwaukee County Highway Commission, Milwaukee, Wis.
Robison, R. D. (Associate re-election), Commonwealth and Southern Corporation, Jackson, Mich.
Stout, C. H., Schweitzer and Conrad Inc., Chicago, Ill.
Walters, W. W., Illinois Bell Telephone Company, Chicago, Ill.
Winterringer, R. T., James Stewart and Company, Inc., Chicago, Ill.
Zimmerman, W. R., Public Service Company of Northern Illinois, Maywood, Ill.

6. North Central

DeBaun, H. L. (Member), U. S. Engineers, Lowry Field, Denver, Colo.
Hills, W. B., United States Army, Fort F. E. Warren, Wyo.
Miller, H. D., The Central Nebraska Public Power and Irrigation District, Hastings, Nebraska.
Pappas, C., 2424 T Street, Lincoln, Nebraska.
Rook, C. W., University of North Dakota, Grand Forks, N. Dak.

7. South West

Downey, J. J., Dallas Power and Light Company, Dallas, Tex.
Green, F. S., Frank Adam Electric Company, St. Louis, Mo.
Hardy, C. H., Southwestern Bell Telephone Company, Wichita, Kansas.
Johnson, H. R., Appleton Electric Company, Dallas, Tex.
Poole, G. C., P. O. Box 1, Marlin, Tex.

8. Pacific

Adams, D. K., United States Army, c/o Postmaster, San Francisco, Calif.
Fayer, W., Bureau of Power and Light, Los Angeles, Calif.
Fleisner, C. L., Stoddart Aircraft Radio Company, Hollywood, Calif.
Furlong, L. R., Navy Department, San Francisco, Calif.
Gustafson, H. C., Pacific Gas and Electric Company, San Francisco, Calif.
Hunt, H. H., Fleet Operation Base, Roosevelt Base, Terminal Island, Calif.
Loper, W. B. (Member), California Electric Power Company, Riverside, Calif.
Mascovich, J. S., Joseph Bonadiman and Associate, Los Angeles, Calif.
Sorteberg, J. (Member), Basic Magnesium, Inc., Las Vegas, Nev.
Tugby, E. E. (Associate re-election), Pacific Electric Manufacturing Corporation, San Francisco, Calif.

9. North West

MacFarlane, J. C., Siems, Drake, Puget Sound, Seattle, Wash.
McKinney, H. H., The Austin Company, Seattle, Wash.
Moen, A. J., Washington Water Power Company, Spokane, Wash.
Olson, A. M., U. S. Army Engineers, Salt Lake City, Utah.

10. Canada

Clarke, G. T., Royal Canadian Signal Corps, Vimy Barracks, Kingston, Ont.
Farnham, D. M. (Member), Montreal Light, Heat and Power Consolidated, Montreal, Que.
Garcia, P. B., Royal Canadian Signal Corps, Vimy Barracks, Kingston, Ont.
Hyde, G., Royal Canadian Signal Corps, Vimy Barracks, Kingston, Ont.
Leuthold, A. (Member), Swiss Electric Company of Canada Ltd., Montreal, P. Q.
Way, W. R. (Member), Shawinigan Water and Power Company, Montreal, P. Q.

Total, United States and Canada, 94

Elsewhere

Borgis, A. G., H. M. Dockyard School, King's College, Portsmouth, England.
Campbell, I. R., Power Station, Tarata Taranaki, New Zealand.
Dunster, M. R., Hydro Electric Commission, Hobart, Tasmania, Australia.
Hinojosa, J. A., Instituto Politecnico Hinojosa, Inc., Cochabamba, Bolivia, South America.

Total, elsewhere, 4

Report of the Board of Directors

THE BOARD OF DIRECTORS of the American Institute of Electrical Engineers presents herewith to the membership its 58th annual report, for the fiscal year ending April 30, 1942. A general balance sheet showing the condition of the Institute's finances on April 30, 1942, together with other detailed financial statements, is included herein. This report contains a brief summary of the principal activities of the Institute during the year, more detailed information having been published from month to month in *Electrical Engineering*.

BOARD OF DIRECTORS' MEETINGS

The board of directors held five meetings during the year, four in New York, N. Y., and one in Toronto, Ont.

Information regarding many of the more important activities of the Institute which have been under consideration by the board of directors and the committees is published each month in the section of *Electrical Engineering* devoted to Institute activities.

DEFENSE AND WAR ACTIVITIES

In accordance with a resolution adopted by the board of directors on June 27, 1940, offering the services of the Institute to the President of the United States in connection with national defense problems, the board, committees, Sections, and headquarters staff have co-operated fully at every opportunity.

In addition to the organization of a committee on national defense, and a committee on civil protection, the Institute appointed a representative on the National Technological Civil Protection Committee and five representatives on the Engineers' Defense Board.

Co-operation has been extended in many undertakings, including the National Roster of Scientific and Specialized Personnel, census of engineering construction firms, extension of subcontracting plans, study of supply of and demand for engineers, and others.

President D. C. Prince delivered his address on the subject of postwar planning at meetings of many Sections and other organizations, and it was received with keen interest.

Editor G. Ross Henninger has contributed a substantial amount of his time weekly, since January 23, 1942, to the United States Navy Department, in Washington, in the organization of an editorial and publication review section for the coordination of Navy technical material.

Assistant Editor W. R. MacDonald, Jr., as a first lieutenant in the United States Army Signal Corps Reserve, was called into active service in January 1941 and has since been promoted to the rank of captain. He is responsible for the preparation and distribution of technical material used throughout the Signal Corps.

PRESIDENT'S AND NATIONAL SECRETARY'S VISITS

President Prince and National Secretary H. H. Henline attended the summer and Pacific Coast conventions, winter convention, South West District meeting in St. Louis, Mo., Southern District meeting in New Orleans, La., and the North Eastern District meeting in Schenectady, N. Y. President Prince and National Secretary Henline will attend the summer convention in Chicago, Ill. In May, the president will visit the Cleveland Section, and the national secretary will visit the Rochester Section.

Places Visited by President Prince

Alabama
Alabama Section, Birmingham
Muscle Shoals Section

Arizona
Arizona Section, Phoenix

California
Los Angeles Section
San Diego Section
San Francisco Section

Colorado
Denver Section
Conference on student activities, North Central District (6), Fort Collins

District of Columbia
Washington Section

Georgia
Georgia Section, Atlanta

Kentucky
Louisville Section

Louisiana
Southern District meeting, New Orleans

Maryland
Maryland Section, Baltimore

Massachusetts
Boston Section
Pittsfield Section

Michigan
Michigan Section, Detroit

Missouri
South West District meeting, St. Louis

New York
New York Section
Syracuse Section
North Eastern District meeting, Schenectady

Ohio
Cincinnati Section and University of Cincinnati Branch, joint meeting.

Oklahoma
Tulsa Section

Oregon
Portland Section

Pennsylvania
Erie Section
Lehigh Valley Section, Scranton
Philadelphia Section
Pittsburgh Section, and University of Pittsburgh, Carnegie Institute of Technology, and West Virginia University Branches, joint meeting

Tennessee
East Tennessee Section, Athens
Memphis Section

Texas
Houston Section
New Mexico-West Texas Section, El Paso
North Texas Section, Dallas
South Texas Section, San Antonio

Washington
Seattle Section
Spokane Section

Yellowstone National Park
Pacific Coast convention
Conference on student activities, Districts 8 and 9

Canada
Summer convention, Toronto
Vancouver Section
Engineering Institute of Canada, Montreal

Mexico
Mexico Section, Mexico City

Places Visited by National Secretary Henline

Indiana
South Bend Section
University of Notre Dame Branch, South Bend

Louisiana
Southern District meeting, New Orleans
Southern District executive committee meeting
Southern District conference on student activities

Massachusetts
Worcester Section

Missouri
South West District meeting, St. Louis

Nebraska
Nebraska Section, Omaha

New York
Ithaca Section
North Eastern District meeting, Schenectady

North Carolina
North Carolina Section, Durham

Ohio
Columbus Section

Virginia
Virginia Section, Richmond
University of Virginia Branch, Charlottesville

West Virginia
West Virginia Section, Charleston

Wisconsin
Madison Section

Yellowstone National Park
Pacific Coast convention
Conference on student activities, Districts 8 and 9

Canada
Summer convention, Toronto
Engineering Institute of Canada, Montreal

ANNUAL MEETING

The annual business meeting of the Institute was held on Tuesday morning, June 17, 1941. The annual report of the board of directors for the fiscal year which ended April 30, 1941, was presented in abstract by the national secretary. A report on the finances of the Institute was presented by National Treasurer W. I. Slichter. The report of the committee of tellers upon the election of officers for the year beginning August 1, 1941, was presented, and President-Elect Prince responded to his introduction with a brief address. During this session, there was an address by Doctor Thomas H. Hogg, chairman and chief

engineer of the Hydro-Electric Power Commission of Ontario, and the Lamme Medal for 1940 was presented to Doctor Comfort A. Adams, consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa.

NATIONAL CONVENTIONS

Three national conventions were held during the year, and a brief report on each follows:

Summer Convention. The 57th summer convention was held in Toronto, Ont., June 16–20, 1941. In addition to the annual business meeting, and conference of officers, delegates, and members, there were ten technical sessions, five technical conferences, and one general session, at which Howard Coonley, of the Walworth Company, gave an address entitled "Making Democracy Work." Entertainment features of the convention were an English tea, bridge, dance, banquet, and golf and tennis tournaments. Many inspection trips were held. The registration was 1,203.

Pacific Coast Convention. The 29th Pacific Coast convention was held in Yellowstone National Park, August 27–29, 1941, with a registration of 322. A conference on "After the Emergency, What?" was a feature of the program, which also included three technical sessions, two technical conferences, one general session, two student sessions, and a conference on student activities. Entertainment features included an informal dinner and dancing, boat trip, inspection trips, and ladies' events.

Winter Convention. The 30th winter convention was held in New York, N. Y., January 26–30, 1942, with a program including 20 technical sessions, at which more than 70 papers were presented, and 6 technical conferences. At the general session, N. G. Symonds, consultant on co-ordination of conservation orders, War Production Board, gave an address entitled "The Engineer's Contribution to the War Effort," and the Alfred Noble Prize was presented to Robert F. Hays, Jr. At an evening meeting, the Edison Medal was presented to Doctor John B. Whitehead, professor of electrical engineering, The Johns Hopkins University, Baltimore, Md. A smoker, dinner dance, and events for women guests completed the program. The registration was 1,331.

DISTRICT MEETINGS

South West District Meeting. This meeting was held in St. Louis, Mo., October 8–10, 1941, with 530 members and guests attending. Seven technical sessions, one general session, and two technical conferences were held. An address by E. T. Gushee, executive vice-president, Union Electric Company of Missouri, on "Electric Utilities' Part in National Defense" was given at the general session, and postwar problems were discussed at a general luncheon at which Doctor William McClellan, president, Union Electric Company, presided, and President Prince gave his address on postwar planning. Entertainment features consisted of a smoker, banquet and dance, women's bridge, and many inspection trips.

Southern District Meeting. The fourth meeting of this District was held in New Orleans, La., December 3–5, 1941. One general session, two technical sessions, and two student sessions were held at which eight papers were presented, in addition to the annual District conference on student activities. Entertainment consisted of a banquet, dancing, golf, and many inspection trips. The attendance was 384.

North Eastern District Meeting. This meeting, held in Schenectady, N. Y., April 29–May 1, 1942, was of wide interest on account of the quality and diversity of the program. There were one general session, three technical sessions, seven conferences, one student session, a joint luncheon with the Schenectady section of The American Society of Mechanical Engineers, a conference on student activities, a banquet, the Steinmetz memorial lecture, inspection trips, and other features. Attendance was about 500.

SECTIONS

During the year, the Sections committee recommended to Section chairmen that (*a*) plant engineers groups be formed, especially in the industrial centers, (*b*) efforts be made by the Sections to reinterest executives no longer engaged in technical work, (*c*) consideration be given to the desirability of organizing local engineering councils, and having some Section meetings devoted to civic affairs or related nontechnical subjects, (*d*) the Sections send announcements of their meetings to their members serving in the armed forces, (*e*) the Sections encourage their members to take keen interest in the development of plans for return to peacetime conditions, and (*f*) the interest in student guidance work in the Sections be increased.

President Prince gave his address on postwar planning at meetings of many of the Sections, and the keen interest with which it was received produced extensive discussions.

At its January meeting the board of directors voted to assign to Sections all remaining unassigned territory within the United States.

A majority of the Sections included in their programs during the year various phases of war activities.

Table I contains information regarding Sections and Branches and their meetings during the past several years. Detailed information on their activities of the past year may be found in the annual report on Section and Branch activities in the June 1942 issue of *Electrical Engineering*, pages 322–3.

STUDENT BRANCHES

A new Branch was organized at the University of Delaware, bringing the total number to 124.

The committee on Student Branches transmitted to all counselors pamphlet copies of Doctor William E. Wickenden's address "The Second Mile" (*Electrical Engineering*, May 1942, pages 242–7), suggesting that it be brought to the attention of students as an excellent statement of the nature of the engineering profession.

The committee on safety again urged the Branches to hold meetings on safety subjects, and transmitted detailed suggestions regarding such meetings.

The terms of 1,761 enrolled students were expected to expire on April 30, 1942. Of these, 935, or about 53 per cent, applied for admission as Associates.

See references at end of the preceding report on Sections.

General Committees

FINANCE COMMITTEE

In recommending a budget for the current appropriation year beginning October 1, 1941, the finance committee estimated that, in spite of the further loss of overseas revenue and loss from members in the United States enrolled in military service, the income for the current year would be approximately the same as that received during the previous appropriation year ending September 30, 1941, these losses being offset by the continued net increase in the membership of the Institute. So far, this expectation appears to be justified.

Accordingly, the budget was set up on the basis of $337,000, approximately $20,000 more than was expended last year. This has made possible a modest increase in the scope of the Institute activities in many departments including the publication of more technical material, some increases in salary to junior members of the staff and the addition of two people, a more liberal provision for the pension fund, and some increase in provision for travel, particularly for District student conferences. While the budget provides for some increases in expenses in

Table I. Section and Branch Statistics

	For Fiscal Year Ending April 30					
	1937	1938	1939	1940	1941	1942
Sections						
Number of Sections	62	65	67	70	72	72
Number of meetings held	621	624	635	701	703	647
Total attendance	74,950	110,148	85,692	91,949	92,554	78,254
Branches						
Number of Branches	119	120	120	121	123	124
Number of meetings held	1,363	1,334	1,190	1,346	1,163	946
Total attendance	46,121	60,446	53,380	64,972	52,285	37,785

addition to salaries, the budget includes an item of unappropriated funds of about $7,000, which it is anticipated should provide for additional necessary items and also for such further increase in the cost of materials as may take place during the year.

In taking care of the Institute's investment funds, the conservative policy of last year has been continued. About 20 per cent of the funds are invested in common stocks of essential industries and the bulk of the remainder is invested in United States Government bonds. Details of the Institute's investments are shown in Schedule 1 on page 379.

The Institute's healthy financial condition is the result of the policy continued over many years of budgeting expenses on the basis of the anticipated revenue and keeping the expenses within this budget limit. To the accomplishment of this, all parts of the Institute organization, and particularly the staff, have contributed. As a result, there has been built up over the life of the Institute a reserve fund of about $250,000, or about three-fourths of a year's expenses at the current level. In these disturbed times, it is very reassuring to have this modest insurance against any sudden great change in the Institute's income or expenses that might result from the war.

TECHNICAL PROGRAM COMMITTEE

Convention Programs. Three national conventions and three District meetings were held during the year. The total attendance of these six meetings represents a 1.5 per cent decrease as compared with the total attendance of five meetings held during the previous year. The attendance for the present year was unusually good when it is considered that the attendance at three of the meetings of the previous year each established a record over corresponding meetings in respective localities. When compared with the year ending April 30, 1939, in which six meetings were held, the attendance for the past fiscal year represents a 4.0 per cent increase. The 73 technical sessions and conferences at the six meetings were sponsored by 15 different Institute committees. Five of the technical committees held no sessions during the year.

The committee has arranged programs to be of the greatest service to the nation's war effort, in so far as possible. Five sessions and conferences of immediate importance to the war effort were held during the winter convention. These sessions were among the best attended, and in the planning of future programs sessions directly related to problems arising from the war will take precedence.

Civic Affairs Conferences. Several conferences on civic affairs have been held during the year to survey and determine how engineers can render the most effective service in their communities during the war and in the postwar period. In a conference on "After the Emergency, What?" held during the Pacific Coast convention, President Prince presented a plan based on studies made in the General Electric Company with a view to maintaining a high level of production during the peace to follow, and to prevent unemployment. Similar studies of business in various communities, states, and throughout the United States have been encouraged through discussions at subsequent conventions and Section meetings. A conference on "How Can Engineers Render Greater Public Service?" was held during the South West District meeting in St. Louis, Mo. Reports were submitted by 14 local engineering groups or councils on "The Contributions of Local Engineering Councils to Their Communities." Another such conference was held during the winter convention, in which a report of the St. Louis conference was presented by F. A. Cowan, vice-chairman of the technical program committee. "Regional Planning in the State of Pennsylvania" was described by R. H. Smith, deputy secretary, department of commerce, Commonwealth of Pennsylvania. Detailed reports of these two conferences on civic affairs were published in *Electrical Engineering*, March 1942, pages 148–52. Arrangements have been made to hold a similar conference on local engineering councils during the summer convention in Chicago.

Table II. Technical Programs, Last Four Years

	Year Ending April 30			
	1942	1941	1940	1939
Number of national conventions	3	3	2	3
Number of District meetings	3	2	3	3
Registration at national conventions and District meetings	4,274	4,339	3,548	4,100
Number of papers presented	182	195	177	184
Number of papers recommended for *Transactions*	152	167	151	169
Estimated number of pages required for printing papers in *Transactions*	807*	938*	886*	986*
Average length of papers recommended for *Transactions*	5.3	5.72	5.86	5.83
Number of technical sessions	50	46	43	50
Number of technical conferences	23	18	10	12

* Partly estimated.

Restricted Sessions. When subjects on which secrecy is required are discussed, closed committee meetings are held. During the winter convention, a session and conference on air transportation were successfully held with the attendance limited to AIEE members who are United States citizens and a few other strictly accredited individuals.

Conferences. During the war period, especially, technical conferences with a minimum of time-consuming formalities are encouraged. The accompanying tabulation shows that a greater number of conferences has been held during the past year than ever before, bringing their total number to 95 since their origin at the summer convention at Ithaca, N. Y., in 1935. The smaller number of technical papers presented, together with the maintained attendance at conventions, reflect the increasing importance of the conference method in providing up-to-the-minute reports of new developments, and free discussion of controversial questions.

General Sessions. A general session was held at each meeting during the year. Preference has been continued for addresses dealing with the broader problems of the profession, as related to co-operative effort during and after the war period, rather than toward specific technical developments. The general session of the 1942 summer convention will present some of the problems of engineering executives for the consideration of Institute members, through a discussion of "Organization and Management of Large-Scale Engineering Work."

Acknowledgments. The committee gratefully acknowledges the interest and efforts of its members and the work of the chairmen of the technical committees and the members of the headquarters staff.

PUBLICATION COMMITTEE

Electrical Engineering, *Transactions*, and advance pamphlet copies of technical program papers were published during the fiscal year in general on the same basis as for the preceding year.

The program and policy for expediting the publication of AIEE *Transactions* material that was initiated at the summer convention in Swampscott, Mass., in 1940, involved among others three related objectives.

The primary among these objectives was the earlier publication of *Transactions* material. This objective was achieved, effective with the January 1942 issue of *Electrical Engineering*. The first of the 1942 winter convention papers were published in the *Transactions* section of that issue, and the publication of the entire program of winter convention *Transactions* material will be completed with the June 1942 issue of *Electrical Engineering* and the corresponding June "Supplement to *Electrical Engineering*—*Transactions* Section." This latter supplement will, in contrast to the several previous issues, be down to what is considered normal size—200 pages or less. Also normal with respect to content, it will carry all the published discussions of 1942 winter convention papers but only a very few of the papers themselves—those which for some special reason could not be accommodated in the *Transactions* sections of the previous monthly issues of *Electrical Engineering*.

Requirements of the first objective imposed a second—that the publication of all 1941 papers and discussions and those remaining from 1940 be completed with the 1941 *Transactions* and the corresponding issues of *Electrical Engineering*.

This objective was achieved as originally scheduled, although as expected the program resulted in great enlargement of the June and December 1941 "Supplements" and imposed a delay of several weeks in the

completion and distribution of the 1941 *Transactions* volume. These latter manifestations were incidental to the transition in publication procedure, and should not be encountered in the ensuing normal application of the Swampscott program.

A third objective of the Swampscott program was that each annual volume of AIEE *Transactions* should contain all, *and only*, the technical program papers and related discussions presented during the corresponding calendar year and other appropriate record material for that year. The 1942 volume is expected to meet this objective.

The achievement of these desired results imposed many added burdens on the headquarters staff and introduced many transient difficulties into the work of the several committees responsible for the development of technical program material. The publication committee is duly appreciative of the effective co-operation of all parties involved.

World war conditions as of May 1, 1942, have introduced certain problems in the conduct of the Institute's publication service that seem worthy of recording. One of these relates to the matter of censorship-export control of the distribution of the monthly issues of *Electrical Engineering* to members and nonmember subscribers in all foreign countries and territories except Canada. Distribution has been entirely stopped in Asia to Burma, Japan, Netherlands Indies, Philippine and other islands, occupied portions of China, Malayan states, Indo-China, and other enemy-dominated territory; in Europe to all points except Great Britain, Turkey-in-Europe, and Russia. This affects about 230 members and 34 subscribers. Distribution to members and subscribers in Central and South America and the other remaining world points now is being made under export-license control and rigorous limitations imposed by the United States Office of Censorship and the Office of Export Control of the Board of Economic Warfare. Currently this affects about 720 Institute members and 205 subscribers.

MEMBERSHIP COMMITTEE

Membership of the Institute at the end of the fiscal year reached an all-time high record for that date of 18,944 exceeding the former peak year of 1927 by 600 members. This very creditable showing was undoubtedly the result of the hard work and unselfish efforts of the members of the Section membership committees, Branch counselors and members of the national membership committee, comprising approximately 700 Institute members engaged in membership work. This result was made possible to a considerable extent by the splendid response of the members of the Institute at large to the broadcast letter of the chairman, dated October 8, 1941, in which they sent in the names of 989 prospects, many of whom are now members. With the pressure of the war effort and unexpected demands upon the time of membership committee personnel, the amount of effort applied to Institute membership work is another indication of the fine spirit of loyalty which binds members of the Institute together in a national organization of their profession.

Table III shows that the gross increase in membership during the year was 1,863 and that this was reduced to a net increase of 1,058 by membership losses during the year. In the preceding year the gross increase was 1,644, reduced to a net increase of 673 by losses during that year. Analysis of the losses as between these two years is of interest in manifesting effective effort of membership committees in connection with delinquent members.

	Year Ending April 30	
	1941	1942
Resigned	299	211
Dropped	582	484
Total	881	695

Table IV shows the number of applications received from enrolled students and others annually for the past five years. It shows a continuous increase each year. Since applications received during the fiscal year are not all acted upon at the close of the fiscal year, there is no direct check between Tables III and IV. The Branch counselors have co-operated with the committee by writing to graduates and using their influence to procure their applications. The Section membership committees receive from headquarters the cards of graduates residing in their territory and endeavor to interview them with respect to membership.

Table III. Membership Statistics for Fiscal Year Ending April 30, 1942

	Honorary Member	Fellow	Member	Six-Year Associate	Associate	Increase	Total
Membership on April 30, 1941	8	778	4,650	5,890	6,560		17,886
Additions							
New members qualified		3	179	24	1,614	1,820	
Former members reinstated		1	8	10	24	43	
Subtotal		4	187	34	1,638	1,863	
Transfers		37	226	726			
	8	819	5,063	6,650	8,198		20,738
Deductions							
Died	3	22	31	43	11	−110	
Resigned		2	47	93	69	−211	
Dropped		3	45	166	270	−484	
Subtotal	3	27	123	302	550	−805	
Transfers			37	203	749		
	3	27	160	505	1,099		1,794
Membership on April 30, 1942	5	792	4,903	6,145	7,099	1,058	18,944

Table IV. Number of Applications Received From Enrolled Students and From All Others

Year Ending April 30	Students	All Others	Total
1942	971	1,031	2,002
1941	887	1,011	1,898
1940	911	918	1,829
1939	849	872	1,721
1938	739	932	1,671

Table V. Number of Enrolled Students as of April 30

Year	New Applications	Renewals	Total
1942	2,585	3,377	5,962
1941	2,351	3,188	5,539
1940	2,525	2,992	5,517
1939	2,271	2,971	5,242
1938	2,428	2,609	5,037

Table VI. Number of Members in Section Territory Reinstated

August 1, 1941 to April 30, 1942	275
Year beginning August 1, 1940	383
Year beginning August 1, 1939	302
Year beginning August 1, 1938	354
Year beginning August 1, 1937	325

Table VII. Status of Membership Dues as of April 30

Year	Total Membership	Members Fully Paid	
		Number	Per Cent
1942	18,944*	16,595**	87.5
1941	17,886	15,777	88.2
1940	17,213	14,997	87.1
1939	16,605	14,371	86.5
1938	16,078	14,127	87.9

* Of the 18,944 members reported for April 30, 1942, 2,349 were not fully paid. Of this number, 327 names are being carried upon the membership rolls, in an inactive status, in accordance with the resolutions adopted by the Board of Directors in the interest of members in the military service of the United States or allied countries, or members located in such countries unable to remit membership dues at this time. The remainder comprises

1. Members owing dues to April 30, 1941 514
2. Members owing dues to April 30, 1942 1,508

(During the period May 1 to May 20, 1942, 316 members have paid dues to April 30, 1942, reducing the number not fully paid to 1,192.)

** Including 733 Members for Life.

Table V shows data on the number of enrolled students and new applications therefrom for five successive years ending 1942. The improvement in 1942 is especially encouraging.

Tables VI and VIII show additional data on membership which are self-explanatory.

The membership committee continued the organization adopted in the preceding year which provided an advisory subcommittee, comprising committee members within easy reach of New York and thus able to hold more frequent meetings than the whole committee, and a research subcommittee to which were referred committee problems requiring study and research. This organization has been found excellently adapted to the membership committee, and permits of holding but one meeting of the committee as a whole, during the winter convention, when a good attendance is assured.

The Membership Committee Guide, a pamphlet prepared and distributed in the preceding year, which outlines recommended procedure for the conduct of Section membership committee work, has been found very helpful to Section membership committees.

In June 1941, a letter was written to each of the newly elected Section chairmen suggesting the early appointment of Section membership committees, in order that such committees can get an early start. This letter was well received by Section chairmen, and undoubtedly aided in getting membership work started early during the current committee year. This is important because of the time required to get committees organized and working, and the shortness of the period when most effective work can be done.

The research subcommittee has studied

Table VIII. Record of AIEE Membership

Year	Total May 1	Year	Total May 1	Year	Total May 1
1884	71	1905	3,460	1925	17,319
1885	209	1906	3,870	1926	18,158
1886	250	1907	4,521	1927	18,344
1887	314	1908	5,674	1928	18,265
1889	333	1909	6,400	1929	18,133
1890	427	1910	6,681	1930	18,003
1891	541	1911	7,117	1931	18,334
1892	615	1912	7,459	1932	17,550
1893	673	1913	7,654	1933	17,019
1894	800	1914	7,876	1934	15,230
1895	944	1915	8,054	1935	14,269
1896	1,035	1916	8,202	1936	14,600
1897	1,073	1917	8,710	1937	15,308
1898	1,098	1918	9,282	1938	16,078
1899	1,133	1919	10,352	1939	16,605
1900	1,183	1920	11,345	1940	17,213
1901	1,360	1921	13,215	1941	17,886
1902	1,549	1922	14,263	1942	18,944
1903	2,229	1923	15,298		
1904	3,027	1924	16,455		

Table IX. Deaths of AIEE Members Reported in "Electrical Engineering"

Name	Date of Election	Date of Death	Grade at Death	Obituary Notice in Electrical Engineering
Aldrich, W. S.	Associate '92	Dec. 22, 1941	Member	Mar. 1942, p. 167
Anderson, E. F.	Associate '35	Oct. 4, 1941	Associate	Dec. 1941, p. 604
Arnold, B. J.	Associate '92	Jan. 30, 1942	Honorary Member	Mar. 1942, p. 166
Augustinus, P.	Member '27	Nov. 18, 1941	Member	Feb. 1942, p. 96
Babcock, F. H.	Associate '28	Aug. 31, 1941	Associate	Oct. 1941, p. 507
Baker, T. S.	Associate '28	Feb. 27, 1941	Member	May 1941, p. 234
Barker, G. A.	Associate '41	June 18, 1941	Associate	Aug. 1941, p. 411
Barnard, G. H.	Member '26	May 6, 1941	Member	July 1941, p. 356
Belden, J. L.	Associate '36	Oct. 5, 1941	Associate	Mar. 1942, p. 167
Bennett, J. C.	Associate '90	Aug. 2, 1941	Member	Sept. 1941, p. 452
Berg, E. J.	Associate '94	Sept. 9, 1941	Fellow	Oct. 1941, p. 507
Berresford, A. W.	Associate '94	May 30, 1941	Fellow	July 1941, p. 355
Brandenstein, E. W.	Member '37	May 20, 1941	Member	July 1941, p. 356
Budden, D. B.	Member '29	April 19, 1941	Member	July 1941, p. 356
Burbank, E. W.	Associate '25	April 1941	Member	April 1942, p. 213
Canfield, C. E.	Associate '02	July 12, 1941	Member	Sept. 1941, p. 451
Carpenter, H. V.	Associate '03	Nov. 15, 1941	Fellow	Jan. 1942, p. 49
Case, H. M.	Associate '11	Mar. 31, 1941	Fellow	May 1941, p. 234
Clark, F. C.	Associate '12	Oct. 28, 1941	Associate	Feb. 1942, p. 96
Clarke, C. L.	Associate '84	Oct. 9, 1941	Fellow	Nov. 1941, p. 557
Clement, E. E.	Associate '97	Mar. 31, 1941	Fellow	Nov. 1941, p. 557
Combs, R. H.	Associate '13	April 25, 1941	Member	July 1941, p. 356
Conrad, Frank	Associate '02	Dec. 10, 1941	Fellow	Jan. 1942, p. 48
Cooper, D. W.	Associate '40	Sept. 29, 1941	Associate	Mar. 1942, p. 167
Cornell, E. S.	Associate '28	May 14, 1941	Member	July 1941, p. 356
Costello, J. M.	Associate '27	Aug. 15, 1941	Associate	Oct. 1941, p. 507
Crichton, A. N.	Associate '08	Sept. 6, 1941	Member	Oct. 1941, p. 507
Croden, W. T.	Associate '37	Jan. 12, 1942	Associate	Mar. 1942, p. 167
Cunningham, F. J.	Associate '19	April 1941	Associate	June 1941, p. 285
Cunningham, J. H.	Associate '06	Oct. 29, 1941	Associate	Feb. 1942, p. 96
Daugherty, W. W.	Associate '37	Aug. 12, 1941	Associate	Dec. 1941, p. 604
Dillman, C. L.	Associate '36	Apr. 27, 1941	Associate	July 1941, p. 357
Don Carlos, H. C.	Fellow '18	Mar. 29, 1941	Fellow	May 1941, p. 234
Eichberg, F.	Fellow '28	July 30, 1941	Fellow	Sept. 1941, p. 451
Elliott, F. F.	Associate '19	May 8, 1941	Associate	Dec. 1941, p. 604
Emmet, W. L.	Associate '93	Sept. 26, 1941	Honorary Member	Nov. 1941, p. 557
Fraser, W. W.	Associate '21	Mar. 31, 1941	Member	July 1941, p. 356
Gherardi, B.	Associate '05	Aug. 14, 1941	Fellow	Sept. 1941, p. 450
Gerry, M. H.	Associate '93	Dec. 30, 1941	Fellow	Apr. 1942, p. 213
Gibney, E. L.	Member '40	Feb. 26, 1942	Member	Apr. 1942, p. 214
Gladson, W. N.	Associate '98	Oct. 18, 1941	Member	Jan. 1942, p. 49
Guillou, A. V.	Member '27	Dec. 1940	Member	Sept. 1941, p. 451
Hall, C. E.	Associate '09	Feb. 16, 1941	Associate	July 1941, p. 356
Harley, E. A.	Associate '06	July 9, 1941	Associate	Sept. 1941, p. 452
Hehre, F. W.	Associate '13	July 27, 1941	Fellow	Sept. 1941, p. 452
Henshaw, F. V.	Associate '89	Mar. 23, 1941	Member	May 1941, p. 233
Imlay, L. E.	Associate '00	June 9, 1941	Fellow	July 1941, p. 355
Irwin, E.	Associate '12	Nov. 3, 1941	Associate	Jan. 1942, p. 49
Kemp, C. G. R.	Member '34	Nov. 3, 1941	Member	Jan. 1942, p. 49
Koch, P. W.	Associate '28	Sept. 2, 1941	Associate	Mar. 1942, p. 167
Kovediaeff, B. E.	Associate '28	April 1941	Associate	Mar. 1942, p. 167
Lacerte, W. J.	Associate '28	Oct. 12, 1940	Associate	Sept. 1941, p. 452
Lanier, A. C.	Associate '04	Feb. 26, 1942	Fellow	Apr. 1942, p. 213
Lawler, G. S.	Associate '11	Oct. 31, 1941	Member	Dec. 1941, p. 604
Leonard, E.	Associate '08	July 24, 1941	Fellow	Oct. 1941, p. 507
Lloyd, M. G.	Associate '26	Apr. 26, 1941	Fellow	June 1941, p. 295
Lyle, R. E.	Associate '32	Apr. 20, 1941	Associate	Sept. 1941, p. 452
MacNaughton, A. K.	Associate '21	March 1941	Fellow	May 1941, p. 234
Magnuson, C. E.	Associate '05	July 10, 1941	Fellow	Aug. 1941, p. 411
Mahaney, D. J.	Associate '34	Nov. 28, 1941	Associate	Apr. 1942, p. 214
Marquis, J. B.	Associate '20	June 5, 1941	Associate	Jan. 1942, p. 49
McDougall, S.	Associate '34	Dec. 23, 1941	Associate	Mar. 1942, p. 167
Morganthaler, P. C.	Associate '09	Mar. 29, 1941	Associate	July 1941, p. 356
Morton, G. L.	Associate '08	Apr. 26, 1941	Fellow	June 1941, p. 295
Moser, F. L.	Associate '25	Mar. 25, 1941	Member	May 1941, p. 234
Mulligan, F.	Associate '29	Feb. 6, 1941	Member	May 1941, p. 234
Murray, W. S.	Associate '03	Jan. 9, 1942	Fellow	Feb. 1942, p. 96
Murrie, J. L.	Member '41	Aug. 16, 1941	Member	Nov. 1941, p. 557
Nyswander, R. E.	Member '22	Apr. 8, 1941	Member	June 1941, p. 295
Otis, J. P.	Associate '27	Feb. 17, 1941	Associate	Sept. 1941, p. 451
Patterson, A.	Associate '08	Apr. 4, 1941	Member	June 1941, p. 295
Patterson, J. H.	Associate '39	July 19, 1941	Associate	Mar. 1942, p. 167
Petterson, R. H.	Associate '37	Jan. 8, 1942	Associate	Mar. 1942, p. 167
Phelps, J. E. B.	Member '29	April 24, 1941	Member	July 1941, p. 357
Plowman, C. S.	Associate '20	Feb. 7, 1942	Associate	Apr. 1942, p. 213
Poirier, A. E.	Associate '01	Dec. 17, 1941	Associate	Feb. 1942, p. 97
Porter, N. M.	Associate '31	May 29, 1941	Associate	Sept. 1941, p. 452
Purdy, H. T.	Associate '13	Jan. 31, 1940	Member	Sept. 1941, p. 451
Richhart, W. S.	Associate '08	Apr. 9, 1941	Member	June 1941, p. 295
Ripley, L. O.	Associate '05	July 22, 1941	Associate	Sept. 1941, p. 451
Roe, J.	Associate '06	Nov. 24, 1941	Associate	Feb. 1942, p. 97
Rothenstein, O.	Associate '28	Oct. 20, 1941	Associate	Feb. 1942, p. 96
Rugg, H. V.	Associate '07	Sept. 21, 1941	Member	Feb. 1942, p. 97
Sampson, F. D.	Associate '06	Aug. 24, 1941	Member	Oct. 1941, p. 507
Sanville, H. F.	Associate '01	May 24, 1941	Member	July 1941, p. 356
Schaefer, R.	Associate '32	Apr. 18, 1941	Member	June 1941, p. 295

(Continued on following page)

Table IX (continued). Deaths of AIEE Members Reported in "Electrical Engineering"

Name	Date of Election	Date of Death	Grade at Death	Obituary Notice in Electrical Engineering
Schalcher, O.	Associate '39	Nov. 3, 1941	Associate	Mar. 1942, p. 167
Schreiber, J. M.	Associate '03	July 18, 1941	Associate	Sept. 1941, p. 451
Schumacher, J. H.	Associate '07	Apr. 1, 1941	Member	May 1941, p. 233
Scott, W. M.	Associate '97	Jan. 19, 1942	Associate	Mar. 1942, p. 167
See, A. B.	Associate '93	Dec. 16, 1941	Associate	Feb. 1942, p. 97
Smith, E. F.	Associate '07	Nov. 13, 1941	Fellow	Feb. 1942, p. 97
Smith, J. C.	Associate '20	July 18, 1941	Associate	Sept. 1941, p. 452
Stebbins, T.	Associate '89	Oct. 14, 1941	Fellow	Nov. 1941, p. 557
Stockbridge, W. A.	Associate '11	Aug. 20, 1941	Associate	Dec. 1941, p. 604
Strike, R. J.	Associate '04	Nov. 2, 1941	Associate	Apr. 1942, p. 214
Swinburne, E. D.	Associate '08	Nov. 12, 1941	Associate	Feb. 1942, p. 97
Torchio, P.	Associate '95	Jan. 14, 1942	Fellow	Feb. 1942, p. 96
Van Gelder, H. M.	Associate '05	Nov. 22, 1941	Member	Feb. 1942, p. 96
Wagner, R. T.	Member '25	Feb. 11, 1942	Member	Apr. 1942, p. 214
Walther, J. T.	Associate '19	Nov. 4, 1941	Member	Jan. 1942, p. 49
Wanamaker, E.	Associate '20	August 1941	Associate	Apr. 1942, p. 214
Ward, H. A.	Associate '35	Recently	Associate	May 1941, p. 234
Whittemore, G. W.	Associate '02	Aug. 22, 1940	Associate	May 1941, p. 234
Yokich, M.	Associate '39	Feb. 12, 1942	Associate	Apr. 1942, p. 214

many problems during the year, the solution of which has contributed to the effectiveness of committee work. One example was its consideration of Doctor Sorensen's suggestion that an effort be made to reinterest members who have developed beyond the "design engineering" stage of their careers and who are now in managerial and executive positions. The result was a letter written to all Institute vice-presidents, District secretaries, and Section chairmen, by the chairman of the Sections committee, soliciting their assistance in a well-defined program for dealing with this problem.

In bringing the advantages of membership to the attention of desirable candidates for admission to the Institute, and in discussions with members about to drop their membership in the Institute, committee members have found that frequently the most effective appeal is that which places emphasis upon the value of the Institute as the national organization of the electrical engineering profession. In relation to present Institute members, and considering the substantial losses each year, it appears that there is opportunity to keep members better informed as to the work and accomplishments of the Institute as a national organization. This problem has also been studied by the research subcommittee and some suggestions have been made for the consideration of the board of directors.

BOARD OF EXAMINERS

The board of examiners held 11 meetings during the past year, averaging about two and one-half hours each, and acted upon 3,662 cases, divided as shown in Table X.

During the past year the board has had the opportunity to put to a practical test the "invitational method" applying to transfer to Fellow grade. This method was recommended by the examiners in December 1940. The first transfers were presented under this procedure in October 1941, and to date 13 cases have been considered, all receiving favorable recommendations. In the opinion of the examiners, all difficulties previously inherent in the Fellow transfer procedure thus have been cleared up.

A survey of the situation with regard to transfer to Member does not under present conditions seem to call for any alteration in the long-established application procedure followed in such cases. The record of the current year shows that of the 246 cases coming before the board only 14 failed to receive a favorable recommendation.

A change in procedure applying to re-elections to Member and Fellow was also put into effect during the past year. Up to April 1941, it had been customary to require applicants for re-election, out of the Institute for more than five years, to supply a new set of references. This requirement was waived in favor of a requirement that all re-election cases be posted in *Electrical Engineering* for a period of one month before formal action is taken, in order to provide for the filing of any possible objections based on ethical grounds, as, except for such ethical objections, a man is always considered eligible for re-election to the grade formerly held.

Table X. Applications for Admission and Transfer

Applications for Admission		
Recommended for grade of Associate	1,169	
Re-elected to the grade of Associate	68	
Not recommended	5	
		1,242
Recommended for grade of Member	167	
Re-elected to the grade of Member	17	
Not recommended	24	
		208
Recommended for grade of Fellow	2	
Re-elected to the grade of Fellow	1	
		3
Recommended for Honorary Member	1	
		1
Applications for Transfer		
Recommended for grade of Member	232	
Not recommended	14	
		246
Recommended for grade of Fellow	28	
Not recommended	0	
		28
Students		
Recommended for enrollment as Students		1,934
Total		3,662

HEADQUARTERS COMMITTEE

In accordance with a request from the board of directors, the committee recommended rules governing the use of AIEE headquarters rooms for meeting purposes. The rules were adopted by the board in January.

INSTITUTE POLICY COMMITTEE

The functions of the committees on economic status of the engineer and legislation affecting the engineering profession were consolidated with those of the Institute policy committee, to be carried out by that committee through subcommittees. During the year, the committee reported to the board of directors on several matters which had been referred to it.

COMMITTEE ON PLANNING AND CO-ORDINATION

A meeting of the committee was held at Institute headquarters in New York on January 27, 1942, at which, after careful consideration and thorough discussion of the probable effects of the war upon the summer convention, the members present unanimously adopted the following recommendations to the board of directors:

1. That the 1942 summer convention be held in Chicago as planned.

2. That the summer convention and technical program committees make it a working convention, with the understanding that the resolution on "summer convention policy" adopted by the board of directors on November 12, 1920, be disregarded in this case.

3. That the summer convention and technical program committees be requested to recommend the most desirable length of program.

At this meeting, the committee considered all requests from District and Section officers for national conventions and District meetings in 1943, and recommended to the board of directors the following schedule of meetings:

Winter convention, New York, N. Y., January 25–29

Summer convention, Cleveland, Ohio, June 21–25

Pacific Coast convention, about September 1; Pacific Coast Districts to be requested to give further consideration to the selection of the most desirable location.

District meetings—Tentative approval given to the following, subject to further review by the District committees or by the board of directors if conditions make it desirable:

North Eastern District (1), Providence, R. I., spring

Southern District (4), Virginia

South West District (7), Kansas City, Mo., spring

All of these recommendations were approved by the board of directors on January 29, 1942.

The committee had, previous to the meeting, considered the request of the Vancouver Section that the 1942 Pacific Coast convention be held in Vancouver, B. C., and, having consulted the vice-presidents of the three Districts concerned, recommended to the board of directors that the convention be scheduled in Vancouver for

September 9–11. This recommendation was approved by the board on October 24, 1941.

COMMITTEE ON CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT

The committee still awaits advice from the joint committee on code of ethics sponsored by Engineers' Council for Professional Development, which has been delayed in its work some four months by the illness of its chairman who also is chairman of this committee. It now is hoped to have completed by the joint committee before the summer is over a report, which then can be considered by the AIEE committee. In association with this, the ECPD committee on professional recognition is endeavoring to formulate a statement of the principles which underlie a code of ethics and which give to ethics a fundamental influence on a profession.

The chairman of the AIEE committee while still ill received a written charge of unethical practices made against an engineer by another engineer, and this will shortly be circulated for consideration by all members of the committee on code of principles of professional conduct.

COMMITTEE ON CONSTITUTION AND BYLAWS

The work of this committee has been limited to a few routine changes in the bylaws. There has been no change in the constitution.

Sections 65, 74, and 83 were modified or deleted in keeping with the action of the board of directors, taken at its meeting of August 8, 1941, to consolidate the work of the committee on economic status of the engineer and the committee on legislation affecting the engineering profession into that of the Institute policy committee.

Section 92 was modified as to date only to make it consistent with the present rules of the John Fritz Medal board of award.

COMMITTEE ON RESEARCH

The committee is now in its second year as a general committee of the Institute rather than a technical committee. As in the preceding year, the principal activity has been that of studying the program of the Engineering Foundation research projects sponsored by the Institute.

One of these, research on the stability of impregnated-paper insulation, project 66, which has been under way for some years at the Johns Hopkins University under the immediate direction of Doctor J. B. Whitehead, will be terminated for the time being at the end of the current year. This termination does not mean that all study desirable regarding this question has been completed, but it does mean that the work is well under way with an indication as to how future work should be done by those who are particularly interested in this problem as it applies to the business of manufacturing apparatus using impregnated-paper insulation. Also, since this research does not have direct bearing upon any war activity, it is believed that it would not be wise to continue it at present.

Another research, on insulating oils and cable saturants, project 74, under way at the Massachusetts Institute of Technology under the immediate supervision of Professor J. C. Balsbaugh, is somewhat newer than project 66 and is now operating on what might be called a production basis. It is recommended that this project be continued at least another year.

The Institute also sponsors jointly with the American Welding Society an extensive welding research program of the Engineering Foundation. This program is so actively supervised by the American Welding Society that the Institute has not undertaken a careful review of it. This does not indicate any lack of interest in electric welding, a science at present so vital to many of our war production activities.

In order that the committee on research may keep in close touch with the technical committees of the Institute and be of service to them when their work indicates that those committees should provide some research program, a research officer, so to speak, has been appointed in each of the technical committees. It is intended that this officer shall be the contact representative between his committee and the committee on research.

Perhaps the one acute problem facing us just now is the production of jewels for meter bearings. This is not definitely an electrical-engineering problem, but jewels for meter bearings are of such great importance to the whole electrical industry that any suggestion leading to the development of a supply of them will be of value.

Should the national situation remind any Institute member of things the committee on research should do, information regarding those recommendations will be welcome and the committee will do its best to turn all promising suggestions into active programs.

COMMITTEE ON SAFETY

The committee has continued its effort to encourage the Student Branches to hold meetings on safety. A circular letter was sent to each Student Branch again at the beginning of the autumn term urging them to hold meetings on safety and suggesting methods of arranging for interesting discussions. Another bulletin was sent at a later date informing them how to borrow two instructive motion-picture films for presentation at meetings on safety. There has been co-operation with the National Safety Council which has conducted a campaign on safety among the colleges.

A survey of the papers published in recent years on electrical safety was undertaken with the result that the committee has in preparation a bibliography of papers and articles on the subject that have been published during the past ten years.

At the suggestion of the committee, there was published in the September 1941 issue of *Electrical Engineering* a paper by G. S. Lawler, entitled "Fires of Electrical Origin in Factories," which had been presented previously at a meeting of the Lynn Section. In this paper, Mr. Lawler emphasized the importance of proper maintenance of electrical apparatus and equipment in prevention of fires and accidents. The committee believes that present war conditions make it more important than ever that electrical installations be maintained in good order.

The committee plans to continue active attention to these and other problems now before it.

Standards

STANDARDS COMMITTEE

While the past AIEE standards year has not been marked by any radically new developments, there was presented to the committee for action a greater-than-normal number of projects. This increase in activity, a continuation of last year's accelerated program, can of course be traced to wartime industrial conditions. The various standards co-ordinating committees and the technical committees of the Institute were equally responsible as the agencies for carrying out this growing program.

Eight projects were approved by the standards committee for publication, as follows:

Standards for Wet Tests, Revised Standards for Measurement of Test Voltages in Dielectric Tests, Revised Standards for Railway Motors, Rating of Electrical Apparatus for Short-Time and Intermittent Duty, Fuses Above 600 Volts, Capacitance Potential Devices, Test Code for D-C Machines, and Test Code for Single-Phase Motors.

The following projects are in various stages of committee development:

Guiding Principles for Selection of Reference and Limiting Values for Standards, Standards for Neutral Grounding Devices, Revised Standard for A-C Power Circuit Breakers, Revised Standard for Lightning Arresters, Revised Report on Standards for Mercury-Arc Rectifiers, Test Code for Impulse Measurements.

The American Standard "Definitions of Electrical Terms," defining over 4,000 electrical and allied terms, is now in the hands of the printer. In furtherance of the desire of the American Standards Association Sectional Committee on definitions to obtain the widest possible distribution for this publication, the AIEE directors authorized a minimum sales price of $1 per copy. This price was made possible only through a quantity production order for 25,000 copies. A national sales campaign is planned, which it is hoped will place not only the entire first edition, but will also require a quantity reprint. Individuals and organizations active in the electrical and allied fields are to be asked to co-operate. It is the belief of those who have given much time and thought to the definitions development that only through placement in the hands of all interested individuals can there be obtained a recognition of the real value inherent in the glossary and a justification for the immense number of man-hours spent in its development.

Two other matters of interest also came to a head during the year: the standards manual, and the standards numbering system. The manual was approved in final revised form and it is hoped will prove of great service in explaining the intricacies of standardization procedure and a valuable guide in future activities.

A study of the numbering systems used

by. AIEE and ASA showed that it is impractical to select any system that will eliminate all inconsistencies. It also became evident that most of the present difficulties will eventually disappear.

The activities of Institute representatives on ASA sectional committees were continued, and in some cases considerably accelerated because of the war effort. Replacement of representatives was found necessary in a number of cases, largely because of occupational shifts. The organization of a new sectional committee on electric fences is now under way. All international standardization activity as carried on by the International Electrotechnical Commission is at a practical standstill as a result of the war. However, it is planned to push standardization as it affects South and Central America. One step in this direction is the proposed translation of Standards into Spanish and Portuguese.

UNITED STATES NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION

The work of the International Electrotechnical Commission, because of the present international situation, has been practically suspended. The central office is being maintained, however, and continues to receive mail at its old address in London, although its valuable records have been moved to a place of safety "for the duration." The United States National Committee of the IEC also is keeping its organization intact and will continue to meet annually so that, as soon as circumstances permit, it will be possible to resume activities.

The USNC at its annual meeting in December 1941 re-elected its officers: E. C. Crittenden, president; L. F. Adams and H. S. Osborne, vice-presidents; Doctor C. H. Sharp, honorary president.

At its annual meeting, the USNC gave further consideration to the desirability of assisting in developing standardization work among the countries of North and South America. As a result of this consideration, the USNC decided to discharge its committee on the subject since the committee's exploration had shown that various other organizations were planning to undertake co-operative work with South American countries and that it seemed best for the USNC to abandon its efforts and to assist where it could the work of other agencies, particularly that of the ASA.

Technical Committees

COMMITTEE ON AUTOMATIC STATIONS

The bibliography on automatic stations covering the period 1932–1940 has been extended to cover 1941, plus a few additional references for 1940, and is now in the hands of the publication committee.

The committee prepared a questionnaire on a-c automatic reclosing equipment applying to stub feeders only. A subcommittee has distributed copies throughout the various Districts, including Canada, and the material collected from this survey will be included in a future report.

A questionnaire on pilot conductors has been received by the relay subcommittee of the committee on protective devices, with which the questionnaire was jointly issued. That subcommittee has issued a preliminary report pertaining to that section of the survey in which it is interested. It is expected that in the near future certain portions of the collected material will be turned over to the committee on automatic stations for classifying the data in which it is interested.

COMMITTEE ON EDUCATION

At the 1941 summer convention, the subcommittee on student guidance reported on its work during the past year. From a questionnaire sent to all the Institute Sections 59 replies were received, of which 20 indicated that those Sections had been carrying on some form of high-school student guidance during the previous year. Of the other 39, 32 stated that they were interested in this kind of work and would welcome suggestions as to how to proceed.

The subcommittee on student guidance was continued for the present year, and an attempt has been made to help those Sections which are interested in carrying on guidance work for the benefit of high-school seniors. The results of this work have not yet come in.

The committee held an informal meeting at the time of the South West District meeting in October 1941, and decided to sponsor an educational session at the winter convention the following January. Three papers were secured and approved for presentation at this convention—one of them for publication in the *Transactions*. The presentation of the papers brought out much interesting discussion.

During the 1942 winter convention, the committee held its annual meeting and discussed the problems of education in the light of the present war emergency. Any move toward the shortening of the academic time spent by students in courses in electrical engineering and any abbreviation of the net content of courses were deplored. The speeding-up of graduation by the elimination of vacations was approved. A resolution to this effect was transmitted to the board of directors, and was approved at the next meeting of the board.

After this meeting, the difficulty of carrying on inspection trips for the benefit of engineering students during the war emergency was discussed and the possibility of showing motion pictures of industrial plants instead was mentioned. A subcommittee on inspection trips was appointed to look into the matter of accumulating information about films that might be secured.

The committee decided to sponsor a discussion session on education at the 1942 summer convention in Chicago, Ill., but to ask for no formal papers on account of the difficulty of getting them written during the war emergency.

For the North Eastern District meeting, the committee approved one paper on the subject of vocational education.

COMMITTEE ON ELECTRICAL MACHINERY

The committee held two meetings during the year, one at the summer convention in Toronto in June 1941, and one at the winter convention in New York in January 1942, at which technical sessions at conventions were discussed and the work of the committee and its subcommittees was reviewed. Plans were made for the 1942 summer convention, to sponsor one symposium on emergency overloading of apparatus and one on mercury-arc rectifiers and their application.

The subcommittee on synchronous machinery has progressed in its work on the revision of the Test Code on Synchronous Machinery and is planning on having the revision prepared and ready for review by June 1942.

The transformer subcommittee continued its co-operation with the ASA committee in the review of the revised ASA Standards on transformers. Papers have been presented and are being prepared for presentation on overloading of transformers for emergency conditions.

The subcommittee on test codes for single-phase motors completed its work on the test code which was submitted to the standards committee. It was issued by the standards committee in November 1941 as the AIEE Proposed Test Code for Single-Phase Motors.

The Test Code for D-C Machines, submitted last year to the standards Committee, was issued by that committee in July 1941.

The subcommittee on rectifiers has, among other things, been studying definitions and a paper was prepared for presentation at the North Eastern District meeting with a view toward unifying terminology. This is of some importance as common practice has not been uniform in terms and meanings in all cases.

The subcommittee on insulation resistance has started work with the object of producing a standard on methods of measuring insulation resistance and a guide for the interpretation of the results obtained.

The committee sponsored one session at the summer convention in 1941 at which five papers on miscellaneous subjects were presented. At the Pacific Coast convention, one paper approved by the committee was presented. At the South West District meeting, one session was sponsored jointly by the committees on electrical machinery and power generation, and several papers on motors were presented. One session on power and machinery and a conference on mercury-arc rectifiers were arranged for the North Eastern District meeting.

COMMITTEE ON ELECTROCHEMISTRY AND ELECTROMETALLURGY

As a result of the pressure of work incident to the war there has been little committee activity during the year. At the meeting held on January 26, 1942, the progress report of the subcommittee on voltage transients in arc-furnace circuits was discussed, and it was voted to continue the study being carried on by the subcommittee. It was requested that any instances of severe transients or short circuits on arc-furnace circuits be reported to N. R. Stansel, subcommittee chairman.

The need for standardization of transformers for electric-arc-furnace operation

was also presented. On motion duly approved, President Prince was requested to appoint a joint subcommittee consisting of representatives of the committee on electrochemistry and electrometallurgy and the transformer section of the committee on electrical machinery to consider the standardization of electric-arc-furnace transformers.

The rapidly increasing demand for electric power by electrothermal and electrochemical plants was discussed. It was pointed out that within the next two to three years these operations will require an additional 20 billion kilowatt-hours per year in the production of aluminum, magnesium, chlorine, stainless steel, and similar war materials.

COMMITTEE ON INSTRUMENTS AND MEASUREMENTS

Two major committee projects were completed. The report on "Telemetering, Supervisory Control, and Associated Circuits," prepared by a joint subcommittee of the committees on automatic stations and on instruments and measurements has been issued in pamphlet form. This encyclopedic report classifies and tabulates the characteristics of the various types of telemetering equipment and should form a useful basis of any future standardization. The report on "Progress in the Art of Metering Electric Energy" prepared by the subcommittee on watt-hour meters was published in serial form in *Electrical Engineering*, beginning with the September 1941 issue and concluding with the December issue. The report is now available in pamphlet form also. It constitutes a complete and authoritative history of the development of the d-c and induction types of watt-hour meters, and includes also a short history of the development of the demand meter.

Technical sessions on instruments and measurements were held at the 1941 summer convention in Toronto and at the 1942 winter convention, at which five, and four papers, respectively, were presented. The committee also sponsored a group of papers stimulated by its subcommittee on dielectric measurements in the field and presented at the session on insulation testing at the 1941 summer convention. The pressure of military work and the confidential nature of new developments probably will seriously curtail the output of technical papers in the immediate future.

In view of the necessity for conserving our energies, a questionnaire was circulated early in the year to stimulate a critical examination of the various standardization activities of the committee. At the fall meeting, it was decided to leave certain lines of work in abeyance and to concentrate on the more pressing problems.

The subcommittee on the revision of AIEE Standard No. 4 has prepared an addition to the table of sphere-gap voltages for 6.25- and 12.5-centimeter spheres which will permit their use up to spacings equal to their diameters. This has been approved by the committee on instruments and measurements and by the standards committee. This subcommittee which is identical in personnel with the corresponding ASA Sectional Committee, remains in readiness for any future standardization in this field.

The subcommittee on definitions has been active in revising certain definitions for the ASA "Dictionary" *C*42 and in securing agreement between these definitions and those used in the "Code for Electricity Meters" and the "Meterman's Handbook."

The subcommittee on current transformers has participated in the revision of section 4 of ASA Standard *C*57 for Transformers, Regulators, and Reactors, in the light of the year's experience with this "Proposed American Standard."

A new subcommittee was appointed to prepare a master code for temperature measurements and has made very good progress.

More recently another subcommittee has been formed to study the report on standards for electrical recording instruments, AIEE No. 40, and to revise it, if necessary, in order that it may be advanced to full standard status.

The committee continues to be represented by liaison members on several other technical committees of the Institute.

COMMITTEE ON MARINE TRANSPORTATION

The activities of this committee have been very greatly curtailed because of war conditions and pressure of work upon all members engaged in shipbuilding and associated industries.

A meeting was held on December 12, 1941. Several changes in Standard No. 45 were approved by the committee, and an addendum issued for the changes approved since the issue of the addenda dated March 20, 1941. The committee has endeavored to keep this Standard up to date to conform to the best practice in shipbuilding. War conditions and scarcity of various materials have necessitated deviation from materials specified therein. The committee decided that such temporary changes should not be incorporated in Standard No. 45. This matter is one that the various manufacturers can best handle to suit their own particular cases.

The subcommittee on wire and cables has been active, and has done considerable work on suggested revisions proposed by the Insulated Power Cable Engineers Association. The purpose of the proposed revisions is to bring the specification for wire and cables in Standard No. 45 more nearly in conformity with the IPCEA standards.

A special subcommittee was appointed to confer with the American Bureau of Shipping on matters relating to the general scope and purpose of Standard No. 45. This matter will require considerable study by the subcommittee before it can be presented to the main committee for consideration. It is doubtful if final action can be taken this year, and it will probably be carried over into the next fiscal year.

COMMITTEE ON POWER TRANSMISSION AND DISTRIBUTION

The committee is now completing the second year of its activities under the new organization with four main subcommittees as follows: substations, transmission, distribution, and general systems. Each subcommittee functions through working groups, the number of which depends on the subject problems coming within its scope.

During the past year, the main committee's activities have been confined largely to sponsoring technical sessions at conventions and reviewing technical papers. The committee sponsored three complete sessions at the winter convention, and likewise is planning three technical sessions at the 1942 summer convention. At the winter convention, one session organized by the committee was devoted to the broad and timely subject, "Distribution Systems in Wartime." Another session was devoted to lightning. One session wholly on cables, and another on lightning, are planned for the summer convention. Other papers sponsored by the committee cover subjects associated directly with the transmission and distribution art, while some cover fields of interest to other committees and are therefore under joint sponsorship.

The proposed revision of Standard No. 41, Insulator Tests, issued in March 1941, is being worked on at the present time with the expectation that it will soon be offered for approval as an AIEE standard. So few comments have so far been received that it is believed this standard can be offered for approval shortly.

The activities of the main committee have been considerably restricted on account of the war conditions; and, as there have not been in evidence problems of immediate concern or importance apparently requiring attention of the committee, the calling of frequent meetings has not seemed justified. Likewise, the work of the subcommittees and working groups has been considerably restricted on account of present wartime conditions. A number of subjects of interest are being considered by these groups, but sufficient progress has not yet been made to report on now.

As many members of the committee are closely associated with problems arising from United States war activities, there has not appeared justification for making heavy demands on the time of these men for committee work which is not mandatory.

COMMITTEE ON PRODUCTION AND APPLICATION OF LIGHT

The committee has continued to keep members of the Institute informed on the latest developments in illuminating engineering, principally through the sponsorship of conferences at District meetings and national conventions and by obtaining articles from qualified authors on illumination subjects for publication in *Electrical Engineering*.

All of these activities have been intensified this year, and plans are now under way to extend them further, especially in those lighting fields which are vital to national defense. A complete report on a conference on civilian-defense lighting held during the 1942 winter convention appeared in *Electrical Engineering* for March 1942, pages 155–6.

A conference on lighting for production is now under consideration for the summer convention in June 1942. Prominent speakers from Canada and the United States will be asked to prepare discussions on this subject which is vital to the defense of each country.

In addition to reviewing all papers on the subject of lighting which are presented for consideration by the technical program committee, and selecting timely lighting subjects and encouraging competent authors to prepare articles for *Electrical Engineering*, this committee also sponsors in *Electrical Engineering* brief summaries and photographs of notable lighting installations.

COMMITTEE ON PROTECTIVE DEVICES

The committee held three meetings during the year and probably will hold another at the 1942 summer convention. Attendance was good, and the discussions dealt mainly with new and revised standards, apparatus insulation levels, temperatures for various types of switchgear, subcommittee reports on subjects under consideration, and papers proposed for technical sessions.

In keeping with the preparedness and war effort, the committee has attempted to bring to completion as rapidly as possible work on the various Standards under its jurisdiction. This appeared very desirable and necessary in order that production during the war period can be based on Standards which reflect proper requirements and present practice. Two new Standards (Nos. 31 and 32) were prepared, approved, and transmitted to the standards committee with recommendation for approval and publication as AIEE Standards. Four Standards (Nos. 19, 22, 27, and 28), which had been issued the previous year for trial use, were completely reviewed and recommended revisions approved. Two other Standards (Nos. 24 and 25) were reviewed. One was recommended to be left unchanged for the time being and work on revision of the other has not been completed.

The major work of the committee was divided among subcommittees: on circuit breakers, switches, and fuses; fault-current limiting devices; lightning arresters; and relays.

The reports of the subcommittees indicate that very substantial progress has been made, especially when it is realized that all members have had unusually large demands on their time for war purposes in connection with their regular work. Consequently, their participation in committee activities, while active and co-operative, have been under somewhat of a handicap.

The following three reports covering a decade of progress in the art were completed and published in *Electrical Engineering:* "Ten Years of Progress in Circuit Interrupters" November 1941; "Ten Years of Progress in Relaying," December 1941; "Ten Years of Progress in Lightning Protection," April 1942.

The committee also has been responsible for the preparation of two extensive bibliographies in its field. One, covering relay literature for the period 1927–39, was prepared by the relay subcommittee and issued as a special Institute publication in July 1941. The second, a comprehensive bibliography on circuit-interrupting devices, including circuit breakers, enclosed switchgear, air switches, bus bars, and fuses, and covering the period 1928–40, is currently in process of publication.

The committee sponsored 13 papers at the 1941 summer convention, 7 at the Pacific Coast convention, 2 at the South West District meeting, one at the Southern District meeting, 19 at the 1942 winter convention, and 1 at the North Eastern District meeting.

The future work of the committee may logically follow along lines of endeavor similar to those of the past. In view of the industry needs, every effort should be made to complete at an early date the proposed standard on distribution-type protector tubes and the revision of Standard No. 25, Fuses Above 600 Volts, as well as the technical report dealing with the subject of selection of neutral-grounding-device impedance.

Awards

COMMITTEE ON AWARD OF INSTITUTE PRIZES

Four national and 11 District prizes were awarded for papers presented during the calendar year 1941 and for the student papers presented during the academic year ending June 30, 1941.

A large number of eligible papers, which were of good quality, were considered, and in determining the awards for the national best paper prizes and the initial paper prize the committee had the benefit of the gradings and recommendations of the technical committees which reviewed the papers. In addition to the four papers awarded national prizes, eight other papers were given honorable mention.

The changes made in the rules on award of "National and District Prizes," issued in the new edition of January 1941, have been in effect for more than an entire year, and have been found to be working satisfactorily.

EDISON MEDAL

The Edison Medal, which is awarded by a committee composed of 24 members of the Institute, was awarded for 1941 to Doctor John Boswell Whitehead, "for his contributions to the field of electrical engineering, his pioneering and development in the field of dielectric research, and his achievements in the advancement of engineering education," and was presented on January 28, 1942, during the winter convention. The medal may be awarded annually for "meritorious achievement in electrical science, electrical engineering, or the electrical arts."

LAMME MEDAL

The Lamme Medal committee awarded the medal for 1941 to Forrest E. Ricketts, vice-president, Consolidated Gas Electric Light and Power Company, Baltimore, Md., "for his contribution to the high reliability of power-supply systems, especially in the design of apparatus for selective relaying and circuit recloser." Arrangements are being made for the presentation of the medal at the summer convention in Chicago, Ill., June 22–26, 1942. The medal may be awarded annually to a member of the AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery."

JOHN FRITZ MEDAL

The John Fritz Medal board of award, composed of representatives of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE, awarded the 38th medal (for 1942) to Everett Lee DeGolyer, consulting petroleum engineer, Dallas, Tex., and a past president of AIME, for "pioneer work in the application of geophysical exploration to the search for oil fields."

HOOVER MEDAL

The Hoover Medal was established through a trust fund created by a gift from Conrad N. Lauer, and is to be awarded periodically "to a fellow engineer for distinguished public service" by a board representing the national societies of civil, mining and metallurgical, mechanical, and electrical engineers. The fifth medal, for 1941, was awarded to D. R. Yarnall, cofounder and chief engineer, Yarnall-Waring Company, Chestnut Hill, Pa., a member of ASME and a past president of United Engineering Trustees.

ALFRED NOBLE PRIZE

This prize, established in 1929, consists of a certificate and a cash award from the income from a fund contributed by engineers and others to perpetuate the name and achievements of Alfred Noble, past president of ASCE, and of the Western Society of Engineers. It may be made to a member of any of the co-operating societies, ASCE, AIME, ASME, AIEE, or WSE, for a technical paper of particular merit accepted by the publication committee of any of these societies, provided the author, at the time of such acceptance, is not over 30 years of age. The award for 1940–41 was presented to R. F. Hays, Jr. (A'36), Sperry Gyroscope Company, Garden City, N. Y., for his paper "Development of the Glow Switch" (published in AIEE *Transactions*, volume 60, 1941, May section, pages 223–6).

WASHINGTON AWARD

The Washington Award for 1942 was bestowed upon William Lamont Abbott (F'13) retired chief operating engineer, Commonwealth Edison Company, Chicago, Ill., and a past president of both ASME and WSE, "for advancing the standards of the engineering profession for service to higher education for aiding combustion research," and was presented to him at a dinner on February 26, 1942. This award may be made annually to an

engineer by the commission of award composed of nine representatives of the Western Society of Engineers and two each of ASCE, AIME, ASME, and AIEE.

CHARLES LE GEYT FORTESCUE FELLOWSHIP COMMITTEE

The committee met in March to decide upon the award of the fellowship for the year 1942–43. In view of the very small number of candidates, with a further possibility that any one of them might be called for some form of service with the government, it was decided that no fellowship would be awarded this year. This action is the same as was taken last year for similar reasons.

Joint Activities

UNITED ENGINEERING TRUSTEES, INC.

This organization is the corporate body which holds title in the name of the four Founder Societies to their joint physical properties, namely, the Engineering Societies Building, the Engineering Societies Library, and the endowment funds of the Engineering Foundation. It operates and manages the Engineering Societies Building, and administers certain joint activities of the four Founder Societies.

The building is fully occupied by the Founder Societies and associates. During the year, certain changes were made to improve the services to members of the societies and others, notably improvement in the illumination of the library by the installation of fluorescent lamps, changes in elevator doors on several floors, reconstruction of one floor to provide a greater number of offices, and the change of the electricity supply system from direct to alternating current.

An abstract of the annual report of the corporation for the year which ended September 30, 1941, appeared on pages 56–57 of *Electrical Engineering* for January 1942.

ENGINEERING FOUNDATION

The Engineering Foundation is a joint organization of the national societies of civil, mining and metallurgical, mechanical, and electrical engineers established for "the furtherance of research in science and engineering, and the advancement in any other manner of the profession of engineering and the good of mankind." It assists in a wide range of research projects of interest to science, engineering, industry, and the general public, each project being under the sponsorship of one of the Founder Societies.

Under the sponsorship of the Institute, the Foundation has continued to support the research on stability of impregnated-paper insulation, at the Johns Hopkins University, the research on insulating oils and cable saturants, at the Massachusetts Institute of Technology, and the welding research, the latter under joint sponsorship with the American Welding Society.

A comprehensive abstract of the annual report of the Engineering Foundation for the year which ended September 30, 1941, appeared on pages 57–59 of *Electrical Engineering* for January 1942.

ENGINEERING SOCIETIES LIBRARY

The Engineering Societies Library, which was formed by combining the separate libraries of the four national societies of civil, mining and metallurgical, mechanical, and electrical engineers, and the preparation of a composite card catalog, probably constitutes the best collection of its type in the United States.

On September 30, 1940, the library had 152,263 volumes, 7,755 maps, and 4,492 searches. Books and pamphlets totaling 3,021 were received during the year ending at that time. Current issues of 1,124 periodicals were received. About 20,000 entries were added to the index of periodicals, which now contains over 260,000 cards.

Special services rendered by the library include: photoprints, searches, abstracts, translations, bibliographies, book loans by mail, and others. The library board has been considering means by which members might be more adequately informed regarding the services available.

An abstract of the annual report of the library appeared on pages 59–60 of *Electrical Engineering*, January 1942.

EMPLOYMENT SERVICE

Operating as an incorporated non-profit-making organization, the Engineering Societies Personnel Service, Inc., assists members of the Founder Societies desiring to secure new positions, and conversely assists employers searching for engineers. Nonmembers may receive such assistance when positions available cannot be filled by members.

Offices are operated in New York, N. Y., Detroit, Mich., Chicago, Ill., and San Francisco, Calif., with the co-operation of the Engineering Society of Detroit in that city, the Western Society of Engineers in Chicago, and the Engineers Club of San Francisco in that city.

The service is supported by the joint contributions of the societies and the individuals who secure positions. An analysis of registration and placement records as reported to the national societies is given in table XI.

ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

This Council, organized in 1932 to engage in activities leading toward the enhancement of the professional status of the engineer, includes three representatives of each of the eight participating organizations, which are the national societies of civil, electrical, mechanical, and mining and metallurgical engineers, the Society for the Promotion of Engineering Education, the National Council of State Boards of Engineering Examiners, and the Engineering Institute of Canada. Its principal activities have been carried on by four committees: student selection and guidance, engineering schools, professional training, and professional recognition.

Including the actions on engineering curricula taken on October 30, 1941, the record is:

Total curricula submitted, including reinspections	896
Accredited	460
Accredited provisionally	105
Not accredited	167
Reinspections with no change in status	132
Action pending	6

A comprehensive report on the annual meeting held on October 30, 1941, and a complete list of accredited curricula appeared on pages 606–10 of *Electrical Engineering* for December 1941.

JOINT CONFERENCE COMMITTEE

Upon recommendation of the committee on planning and co-ordination, the board of directors authorized the president and national secretary to join with like officers of the other Founder Societies in an informal conference committee to meet whenever deemed advisable to consider joint efforts in national defense and other matters. The committee met in Indianapolis, Ind., Washington, D. C., Montreal, Que., and Roanoke, Va.

In accordance with its recommendations, the societies organized a joint committee on postwar planning and a joint committee on

Table XI. Analysis of Employment Service

Month	Men Registered					Men Placed				
	New York	Chicago	San Francisco	Detroit	Total	New York	Chicago	San Francisco	Detroit	Total
1941										
May	154	67	86	23	330	61	21	30	12	124
June	193	100	68	79	440	52	20	24	22	118
July	151	84	61	60	356	63	31	26	15	135
August	126	94	76	56	352	41	17	45	15	118
September	144	66	50	43	303	38	15	32	12	97
October	156	84	65	34	339	37	22	16	10	85
November	139	66	46	42	293	37	15	32	10	94
December	113	49	41	28	233	45	18	27	11	101
1942										
January	160	65	58	32	315	41	20	40	12	113
February	148	51	50	37	286	31	29	19	14	93
March	139	60	67	32	298	43	26	34	16	119
April	138	44	49	26	257	49	29	23	10	111
Total	1,763	830	717	492	3,802	538	263	348	159	1,308

inter-American engineering co-operation. It considered various other matters of interest to members of the several societies.

REPRESENTATIVES

In addition to the many divisions of its work represented by its own general and technical committees, the Institute participates in a wide range of activities of interest and importance to engineers and others through its representation upon about 30 joint committees and national organizations.

A list of representatives was published in the September 1941 issue of *Electrical Engineering* and in the 1942 Year Book.

Appreciation

On behalf of the membership, the board of directors expresses its sincere appreciation of the many important contributions to Institute activities made by the national committees and the District, Section, and Branch officers. Despite the extreme difficulties encountered during the past year, and consequent severe restrictions of time available for engineering society activities, enthusiasm for and constructive accomplishment in Institute work have continued at a high level. The continuing keen interest among the members in general has contributed substantially to the accomplishments of the Institute. The board thanks all for their interest and unselfish co-operation.

Respectfully submitted for the board of directors.

H. H. HENLINE
National Secretary

May 22, 1942

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Property and Restricted Funds Securities, Less Reserve for Securities of Doubtful Value, April 30, 1942

Schedule 1

	Principal Amount of Bonds or Number of Shares of Stock	Restricted Funds				Property Fund (Equipment Replacements)
		Reserve Capital Fund	International Electrical Congress Library Fund	Lamme Medal Fund	Total Restricted Funds	
Railroad Bonds:						
Alleghany Corporation 20 year collateral trust convertible 5%, due 1949	$15,000.00	$ 10,627.50			$ 10,627.50	
Baltimore & Ohio Railroad Company 6% refunding and general mortgage series C, due 1995 (stamped)	12,000.00	8,940.00		$4,330.00	13,270.00	
Chicago & Erie Railroad Company 5% first mortgage, due 1982	1,000.00	1,105.00			1,105.00	
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974 (certificates of deposit)	10,000.00*	9,818.75*			9,818.75*	
New York Central Railroad Company 5% refunding and improvement mortgage series C, due 2013	6,000.00	5,742.50			5,742.50	
Northern Pacific Railway Company 6% refunding and improvement mortgage series B, due 2047	10,000.00	10,962.50			10,962.50	
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950 (certificates of deposit)	6,000.00*	5,497.50*			5,497.50*	
Western Pacific Railroad Company 5% series A, due 1946 (stamped)	15,000.00*	7,225.00*			7,225.00*	
Total railroad bonds		$ 59,918.75		$4,330.00	$ 64,248.75	
Public Utility Bonds:						
New York & Queens Electric Light & Power Company 3½% first and consolidated mortgage, due 1965	10,000.00	$ 11,000.00			$ 11,000.00	
Bond and Real Estate Mortgage:						
Fidelity Union Title and Mortgage Guaranty Company first mortgage certificates (on property 75–79 Prospect Street, East Orange, N. J.) 4%, due 1944	14,152.05*	$ 13,208.32*			$ 13,208.32*	$943.73*
United States Government Bonds:						
Treasury Savings bonds series D, due July 1, 1949	10,000.00	$ 7,644.00			$ 7,644.00	
Treasury Savings bonds series D, due January 1, 1950	10,000.00	7,500.00			7,500.00	
Treasury bonds 2%, due 1950/48	77,000.00	78,130.94			78,130.94	
Treasury bonds 2½% due 1972/67	6,300.00	1,100.00	$5,200.00		6,300.00	
Defense bonds series F, due June 1, 1953	34,000.00	25,160.00			25,160.00	
Total United States Government bonds		$119,534.94	$5,200.00		$124,734.94	
Capital Stocks:						
American Can Company	60 shares	$ 4,988.40			$ 4,988.40	
American Telephone & Telegraph Company	30 shares	4,897.95			4,897.95	
Commonwealth Edison Company	200 shares	7,580.68			7,580.68	
Eastman Kodak Company	35 shares	4,768.23			4,768.23	
E. I. du Pont de Nemours Company	40 shares	6,398.20			6,398.20	
General Electric Company	130 shares	4,463.80			4,463.80	
International Harvester Company	100 shares	5,030.50			5,030.50	
International Match Realization Co., Ltd. voting trust certificates for capital shares of International Match Corporation	6 shares*	2,094.15*			2,094.15*	
Standard Oil Company of New Jersey	110 shares	4,791.78			4,791.78	
Union Carbide & Carbon Corporation	70 shares	4,858.35			4,858.35	
Total capital stocks		$ 49,872.04			$ 49,872.04	
Total		$253,534.05	$5,200.00	$4,330.00	$263,064.05	$943.73
*Less reserve in full for the securities designated *, considered to be of doubtful value		$ 37,843.72			$ 37,843.72	$943.73
Total Securities, Less Reserve		$215,690.33	$5,200.00	$4,330.00	$225,220.33	

HASKIN - & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

22 EAST 40TH STREET
NEW YORK

May 15, 1942

American Institute of Electrical Engineers,
33 West 39th Street, New York.

Dear Sirs:

We have made an examination of your balance sheet as of April 30, 1942, and of your recorded cash receipts and disbursements for the year ended that date. Our examination consisted of a review of the system of internal control and of the accounting procedures of the Institute and examination or tests of its accounting records and other supporting evidence by methods and to the extent we deemed appropriate. We present the following:

Balance Sheet, April 30, 1942 (Exhibit A).
Property and Restricted Funds Securities, Less Reserve for Securities of Doubtful Value (Schedule 1).
Statement of Recorded Cash Receipts and Disbursements of Operating Fund for the Year Ended April 30, 1942 (Exhibit B).
Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1942 (Exhibit C).

In our opinion, the accompanying Exhibit A fairly presents your financial condition at April 30, 1942, and the accompanying Exhibits B and C fairly present your recorded cash receipts and your disbursements of funds, as indicated, for the year ended that date.

Yours truly,

(*Signed*) HASKINS & SELLS

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Balance Sheet, April 30, 1942

Exhibit A

ASSETS		
Property Fund Assets:		
One-fourth interest in physical properties of United Engineering Trustees, Inc.:		
Land, buildings, and equipment (less depreciation and renewal reserve)	$385,367.94	
Funded depreciation and renewal reserve	113,080.54	
Total	$498,448.48	
Equipment:		
Library—volumes and fixtures	37,296.37	
Office furniture and fixtures (less reserve for depreciation, $24,973.05)	9,764.34	
Works of art, etc.	3,001.35	
Investment, less reserve in full $943.73—Schedule 1		
Total property fund assets		$548,510.54
Restricted Fund Assets:		
Securities—at cost, less reserve, $37,843.72 (quoted market value, $203,652.82), Schedule 1	$225,220.33	
Cash (Exhibit C)	63,751.26	
Accrued interest receivable	36.25	
Total restricted fund assets		289,007.84
Operating Fund Assets:		
Cash (Exhibit B)	$ 16,633.48	
Accounts receivable:		
Members—for dues (less reserve, $8,000.00)	10,861.98	
Advertisers	1,424.03	
Miscellaneous	4,158.44	
Accrued interest receivable	1,812.04	
Inventories:		
Transactions, etc.	1,277.25	
Text and cover paper	6,492.70	
Work in process (May issue of *Electrical Engineering*, etc.)	6,513.99	
Badges	1,345.97	
Total operating fund assets		50,519.88
Total		$888,038.26

LIABILITIES		
Property Fund Reserves		$548,510.54
Restricted Fund Reserves:		
Reserve Capital fund	$231,211.20	
Pension fund	18,000.00	
Life Membership fund	8,805.91	
International Electrical Congress of St. Louis Library fund	5,358.05	
Lamme Medal fund	4,556.83	
Mailloux fund	1,075.85	
Total restricted fund reserves		289,007.84
Operating Fund Reserves, Liabilities, Etc.:		
Accounts payable	$ 13,113.38	
Deferred income:		
Dues received in advance	4,886.98	
Entrance fees and dues advanced by applicants for memberships	659.60	
Deferred credits for other unallocated receipts	487.55	
Subscriptions for *Transactions* received in advance	45.16	
Reserve for prepaid subscriptions for *Electrical Engineering*	5,066.74	
Operating fund reserves	26,260.47	
Total operating fund reserves, liabilities, etc.		50,519.88
Total		$888,038.26

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Recorded Cash Receipts and Disbursements of Operating Fund for the Year Ended April 30, 1942

Exhibit B

Cash on Deposit With the National City Bank of New York, May 1, 1941		$ 41,617.90
Receipts:		
Dues (including $96,060.00 allocated to *Electrical Engineering* subscriptions)	$212,948.30	
Advertising	59,619.75	
Transactions subscriptions	6,933.62	
Electrical Engineering subscriptions	9,183.16	
Miscellaneous publications (preprints, Standards, *Transactions* index, etc.)	20,114.89	
Students' fees	13,389.00	
Entrance fees	9,420.85	
Membership badges	2,577.19	
Transfer fees	1,663.04	
Interest and dividends on investments of Restricted Capital fund	7,822.83	
Miscellaneous	16.95	
Total receipts		343,689.58
Total		$385,307.48
Disbursements:		
Publications expense:		
Electrical Engineering	$ 95,951.25	
Transactions	19,805.15	
Year Book	6,988.69	
Miscellaneous publications (preprints, Standards, *Transactions* supplement, etc.)	14,566.26	
Institute meetings	13,759.99	
Institute Sections	37,694.33	
Institute Branches	3,446.66	
Edison Medal committee	188.10	
Finance committee	771.23	
Headquarters committee	193.21	
Membership committee	8,828.86	
Pension fund committee	250.00	
Standards committee (including $1,132.43 for "Definitions of Electrical Terms")	9,867.82	
Technical committees	647.96	
Forward	$212,959.51	$385,307.48
Total (forward)		$385,307.48
Disbursements (forward)	$212,959.51	
Traveling expenses:		
Geographical Districts:		
Executive committees	3,863.21	
Vice-presidents	823.38	
Branch counselors and chairmen	10,844.76	
President's appropriation	1,700.78	
Board of directors	6,516.84	
National nominating committee	1,121.49	
Administrative expenses	50,953.79	
Geographical Districts:		
Initial paper prizes	75.00	
Branch paper prizes	340.50	
Institute prizes, national	215.00	
American Co-ordination Committee on Corrosion	25.00	
American Standards Association	1,500.00	
United Engineering Trustees, Inc.:		
Building assessment	10,984.81	
Library assessment	10,182.56	
Engineering Societies Personnel Service, Inc.	1,210.10	
Engineers' Council for Professional Development	1,275.00	
Engineers Defense Board	166.67	
Engineering Foundation Projects:		
Insulating oils and cable saturants	250.00	
Welding research	250.00	
Research on impregnated paper insulation	250.00	
National Fire Protection Association—Dues	60.00	
Membership badges	2,643.40	
Legal services	250.00	
Transfers:		
To Pension fund	8,000.00	
To Reserve Capital fund	40,160.00	
To Life Membership fund	2,000.00	
Miscellaneous	52.20	
Total disbursements		368,674.00
Cash on Deposit With the National City Bank of New York, April 30, 1942		$ 16,633.48

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1942

Exhibit C

	Restricted Funds							Property Fund (Equipment Replacements)
	Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Pension Fund	Total Restricted Funds	
Cash on Deposit With the National City Bank of New York and Various Savings Banks, May 1, 1941	$27,095.95	$3,473.34	$5,289.37	$ 24.00	$1,059.87	$10,000.00	$ 46,942.53	$2,738.98
Receipts:								
Interest on bonds and dividends on stock		$ 144.44	$ 52.43	$624.00			$ 820.87	
Interest on bank balance		53.20			$ 15.98		69.18	
Proceeds from sale of securities	$14,103.83	3,134.93					17,238.76	
Transfer from operating fund	40,160.00	2,000.00				$ 8,000.00	50,160.00	
Miscellaneous								$ 0.19
Total receipts	$54,263.83	$5,332.57	$ 52.43	$624.00	$ 15.98	$ 8,000.00	$ 68,288.81	$ 0.19
Total	$81,359.78	$8,805.91	$5,341.80	$648.00	$1,075.85	$18,000.00	$115,231.34	$2,739.17
Disbursements:								
Purchase of securities	$45,838.91		$5,200.00				$ 51,038.91	
Equipment replacements, alterations, and repairs								$2,739.17
Gold and bronze replicas of Lamme medal and certificate				$229.30			229.30	
Transfer to operating fund—reimbursement of prior years' expenses				211.87			211.87	
Total disbursements	$45,838.91		$5,200.00	$441.17			$ 51,480.08	$2,739.17
Balance on Deposit With the National City Bank of New York and Various Savings Banks, April 30, 1942	$35,520.87	$8,805.91	$ 141.80	$206.83	$1,075.85	$18,000.00	$ 63,751.26	

OF CURRENT INTEREST

War-Production Conference, First of Series, Held at Newark, N. J.

At the request of the War Production Board, American engineering societies are holding a series of war-production conferences "to exchange, examine, and disseminate information and experience on the engineering and management aspects of war-production problems, and the change-over of plants and equipment to war production." The first conference was held May 29, 1942, at Newark, N. J.; it was sponsored jointly by the local sections of 14 technical and engineering societies, including the AIEE New York Section, and the New Jersey Council. Approximately 750 attended. Other conferences, sponsored by other local engineering groups, are being held in other sections of the United States. Each conference is being arranged to fit the particular needs of the area in which it is held, and the discussion leaders come from war plants in that area.

Beginning with an afternoon session, which was addressed by five prominent speakers on various phases of war production, the Newark conference included also a dinner which was addressed by AIEE Past President W. H. Harrison, director of production, War Production Board, Washington, D. C., and a group of seven panel meetings in the evening, dealing with as many different aspects of the subjects.

AFTERNOON SESSION

The "general meeting" of the conference at which R. M. Gates, president, Air Pre-Heater Corporation, presided, included the following four addresses:

Introduction to the Problems of Conversion, George T. Trundle, Jr., president, Trundle Engineering Company.

Shop Problems in Ordnance Manufacture, Colonel J. K. Clement, deputy district chief, New York Ordnance District, United States Army.

Shop Problems in Aircraft Manufacture, Lieutenant-Colonel J. A. McDonell, Eastern Procurement District, United States Army Air Force.

Shop Problems in Manufacture of Naval Equipment, Lieutenant-Commander A. S. Kibbee, U.S.N.R., Office of Inspector of Naval Materiel.

In the introductory address of the afternoon, Mr. Trundle urged industry not to build any new tools that it can get along without, but to find ways and means of utilizing old machinery to produce war equipment. He pointed out that for every man in the armed forces there must be 18 in industry and elsewhere. He spoke of a probable requirement of 60,000,000 workers which would necessitate employing older men, women, and younger men of pre-military age. As one way of overcoming the shortage of skilled craftsmen, he recommended breaking down manufacturing operations so as to utilize less skilled workers.

Colonel Clement contrasted the present ordnance-production program against a normal peacetime program, and outlined production-control procedures and the functions of ordnance-production expediters. He also emphasized the need for prime contractors to render all possible assistance to subcontractors, which comprise mostly the smaller manufacturers who are totally unfamiliar with many of the items they might produce on subcontract. He explained how the Ordnance Department had done advance planning for war during the past 20 years, but that the Department had not anticipated the necessity for the United States becoming the "Arsenal of Democracy." He also discussed the problem of developing appropriate cost data for new war products.

In pointing out that a total of 73 trades or crafts are involved in the manufacture of airplanes, Colonel McDonell said that to relieve the present metal shortage plywood is being used in the manufacture of training and cargo ships. This has introduced new problems in the shop. He said that the engine industry had been well prepared for the present emergency but that the production of superchargers, being comparatively new, had imposed new problems. He discussed in some detail the problem of aircraft instrumentation, calling attention to the many different mechanisms represented in the wide variety of such instruments. Jewell bearings for these instruments, which were largely imported before the war, imposed serious problems; these were solved by altering instrument design to reduce the usage and at the same time expanding our own small jewell-bearing industry. Many women have been employed in this expanded instrument production, which introduced new problems. Colonel McDonell also urged all manufacturers of spare parts to work toward the greatest possible accuracy of dimensions, because of the limited facilities for making adjustments in the field.

Commander Kibbee called attention to the wide variety of products required by the Navy by stating at the outset that a battleship in effect comprises a complete community at sea, except that there is no family life; equipment therefore ranges from huge guns to the jeweled bearings of precision instruments. He also urged industry to make full use of old tools. Pointing out that many tools are not being used to full advantage, many others are being used improperly, and still others are idle, he urged that measures be taken to correct this situation. Commander Kibbee emphasized that new machinists—not new machines—are needed, and urged that engineering ingenuity be applied toward adapting old tools to new uses. He expressed the opinion that many of the problems in the present war production arise from the fact that manufacturers have been taken by surprise, but emphasized that the great need is for production—more production—faster.

DINNER PROGRAM

Following the dinner, which was served to a capacity crowd, AIEE Past President W. H. Harrison, director of production, War Production Board, Washington, D. C., spoke on the subject "More War Production Today and Tomorrow." He was introduced by Myron B. Gordon, vice-president and general manager, Wright Aeronautical Corporation, who acted as toastmaster.

Mr. Harrison said that the nation is *doing* its "impossible" job, and that 40 per cent of our national economy is now going into the war effort. He pointed out that present aircraft production is so far in advance of last year's production as to offer no basis of comparison. He said also that ordnance production is at a level three times the highest level during the first world war, and that it is increasing at the rate of about 30 per cent per month. This, he added, reflects the careful planning that has been carried out by our armed forces.

Mr. Harrison pictured the war-production program as a whole as comprising

three stages. The first consists of the provision of production facilities, which is now virtually complete. He expressed the belief that history will record the completion of this stage of the program in such a short time, considering the enormous expansion of production facilities involved, as a monumental accomplishment. The second stage of the program concerns the procurement of materials, and the third stage the procurement of man power. Materials appear to be the limiting factor in the present stage.

Concerning cost, Mr. Harrison said that while some attention is being given to this important factor, it would have to be considered secondary to getting the job done. He emphasized the need for economy of tools, materials, and man power. In this connection he mentioned the high degree of standardization of products manufactured by different companies that is now being achieved.

Expressing his pride at being a member of the engineering profession, Mr. Harrison said in closing: "Never have I seen more unselfish devotion to a job than among the engineers doing the present war job."

PANEL MEETINGS

The seven panel meetings following the dinner covered: ordnance inspection; machine-shop problems; metallurgical problems; substitute materials, chemical equipment, and plant safety; electrical problems; welding problems; and foundry production. M. P. Hooven and H. B. Snow, both of the Public Service Electric and Gas Company, Newark, N. J., served respectively as chairman and secretary of the panel on electrical problems. Discussion leaders and their subjects were:

Electrical Devices as Production Aids, L. F. Stone (M'30), General Electric Company, Newark, N. J.

Plant Rearrangement for Increased Production, E. J. White (M'26), E. J. White Company, Newark, N. J.

Improving Shop Lighting, O. P. Cleaver (A'36), Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

Power Supply Problems, H. W. Bay, Public Service Electric and Gas Company, Newark, N. J.

Emergency Repairs and Rebuilding Problems, C. E. Eiseman, General Electric Company

Solving Problems in Production of Communication Equipment, H. P. Westman, secretary, Institute of Radio Engineers, New York, N. Y.

Each panel leader spoke briefly on his assigned subject, after which there was a question and answer period featuring an informal general interchange of information on specific current production problems.

The committee on arrangements for the conference was headed by C. A. Hescheles, Brooklyn Union Gas Company, Brooklyn, N. Y. He was assisted by two vice-chairmen: P. T. Onderdonk, War Production Board; and G. J. Nicastro, Combustion Engineering Company. Other members of the committee, which comprised 27 representatives of the various sponsoring societies, included C. C. Whipple, Brooklyn Polytechnic Institute, and M. P. Hooven, Public Service Electric and Gas Company, respectively chairman and secretary of the AIEE New York Section.

Seriousness of Rubber Shortage Portrayed in Joint War-Agency Statement

Four leading war-agency officials recently joined in a statement designed to clarify the facts about the severe rubber shortage. Issued because many confusing and conflicting stories have been circulated about rubber, the statement points out that the shortage is extremely serious, reports to the contrary notwithstanding, and that no rubber of any kind can be spared for purposes not directly connected with the war effort.

Donald M. Nelson, chairman of the War Production Board; Arthur B. Newhall, Rubber Co-ordinator; Joseph B. Eastman, director of the Office of Defense Transportation; and Leon Henderson, Administrator of the Office of Price Administration and director of the WPB Division of Civilian Supply, all joined in the statement. As rubber is one of the scarce materials used widely in electric circuits and equipment, the statement may be of interest to many readers of *Electrical Engineering;* accordingly, the essential substance follows.

"There has been a great deal of confusion about the rubber situation, much of it caused by optimistic stories about the availability of synthetic rubber at an early date, or the large amount of scrap rubber that can be reprocessed. But there is little real basis for such optimism. Our rubber shortage is one of the worst materials shortages we face. We can spare no rubber of any kind for nonessential uses. Statements to the contrary are misleading, and do the country a great disservice, for the facts as we see them are grim, and we need 100 per cent co-operation in conservation measures by the general public and by industry.

"Before Pearl Harbor, it appeared that this country had an adequate supply of rubber, in the light of the situation as it then existed. We had stock-piled substantial tonnages in anticipation of interruption in shipments from the Far East, and steps had already been taken to regulate civilian consumption.

"Events following Pearl Harbor, however, created a wholly new series of problems. The President announced a new military program on January 6. This very greatly increased our military requirements for rubber. Then, our major sources of rubber supply were lost. In addition, our Allies were forced to look to the United States as a source of military rubber.

"Thus, despite precautionary steps taken in 1941, it has become necessary to develop a rationing program for rubber which eliminates all but the most necessary uses. War Production Board figures show three facts:

"1. We cannot spare any rubber to make new tires for ordinary passenger cars; the tires we do have must be strictly rationed to essential uses.

"2. All the synthetic rubber we get must go to the war effort.

"3. The most optimistic estimates for this year and next indicate no rubber for anything but the most essential uses.

"Actually, the rubber shortage is far worse than most people seem to realize; the enemy controls 90 per cent of the world's rubber-producing areas, and every ounce of our stock pile is needed desperately for the armed forces. Worst of all, the optimistic stories may keep us from recognizing what we are up against until too late. Our biggest stock pile of rubber is on our cars; these tires must be preserved. Autos shelved for the duration for lack of tires put more burden on already overcrowded busses and trolleys.

"Every citizen can and must adopt a five-point conservation program:

"1. Stop driving your car except when necessary; make it last.

"2. Drive under 40 miles an hour.

"3. Shift tires from wheel to wheel and inflate them properly.

"4. If you drive to work, drive your friends and neighbors; car-pooling is essential.

"5. Remember that rubber is precious; save it; every car is now a vital part of the nation's transportation system.

"Needless driving today is unpatriotic. Deliberate waste of rubber helps the enemy. We call on Americans to ration themselves strictly.

BACKGROUND

"This is the situation that faces us: The amount of rubber that can be made available for civilian, industrial, and essential transportation purposes this year must be held down to not more than 150,000 tons, which is 79 per cent less than the 700,000 tons consumed for all civilian purposes in 1941. The actual current rate of use—10,000 tons a month—is 83 per cent less than the 1941 rate of civilian consumption.

"The 1942 allotments do not include any rubber for new passenger-car tires, and are restricted to articles essential to the civilian industrial economy, such as bus and truck tires, and certain industrial, medical, and health items.

"It has been reported that some drivers are not taking conservation measures seriously, in the belief that eventually their tires will be requisitioned. But if we wear out the tires on the 30 million passenger cars, the truck, bus, and train transportation systems of the nation will be swamped. On the other hand, if it is possible to preserve cars in the hands of their owners, it will be an advantage to all transportation and to the war effort. If the time should come when the Government had to call on civilians to sacrifice their tires, we know they would respond patriotically. In the meantime, no American should deliberately waste the mileage left in his tires.

"Detailed estimates of our requirements and supplies, for military reasons, cannot be made public. But we have the figures, and the story they tell is a very serious one.

In spite of the excellent job the Army and Navy have done in rearranging specifications to reduce the rubber consumption of military articles, our war machine still eats up huge amounts of rubber.

"It has been necessary, therefore, for the rubber and rubber products branch of the War Production Board to curtail drastically the rubber permitted for civilian articles, and to establish new specifications to reduce the rubber content in essential articles. In addition, the Office of Price Administration has instituted a rationing program for tires, the armed services have adopted conservation regulations, and the Office of Defense Transportation has issued drastic regulations directed toward elimination by commercial operators of waste and unnecessary mileage.

"The following figures show how the war effort demands rubber that must be made available: A medium tank requires 1,750 pounds; a gas mask, 1.8 pounds; a ten-ton pontoon bridge, 3,200 pounds; a half-ton truck, 125 pounds; a Flying Fortress, 1,250 pounds; the pneumatic rafts carried by airplanes, 29 pounds each. So it goes. Rubber is indispensable. We do not usually connect rubber with a ship, but a 35,000-ton battleship alone requires 150,000 pounds—or enough to equip 2,000 passenger automobiles complete with spare tires.

SYNTHETIC RUBBER

"The War Production Board is making every effort to expand the production of synthetic rubber, and is investigating every possible new process, but all the information we have shows that every pound of synthetic rubber which this country will be producing at forced draft between now and the end of 1943 must be reserved for direct and indirect military purposes. None can be made available for the manufacture of tires for nonessential civilian purposes.

"The War Production Board has set a goal of 800,000 tons as the production *rate* to be reached by the end of 1943. Of this, production of Buna S, a butadiene type synthetic is to reach a *rate* of 700,000 tons by the end of 1943. The balance is made up of butyl and Neoprene. But reaching a *rate* of 700,000 tons, of course, is a much simpler thing than actually producing that much rubber in a year.

"The present program calls for production of over 300,000 tons during the calendar year of 1943. In addition the Rubber Co-ordinator's office is studying the possibility of increasing the currently planned production of synthetic rubbers other than the Buna S; but many difficulties remain to be solved.

RUBBER SALVAGE

"All old scrap rubber can be reclaimed and used over again. Reclaimed rubber can be mixed with crude rubber to form a compound usable in many products, military as well as civilian. But we cannot process rubber that is in the basements or back yards or garages of the country. Old tires, tubes, rubber shoes, hose, bathing caps, and other articles must be turned in, in ever increasing quantities, if we are to maintain the capacity of reclaiming plants.

"Since Pearl Harbor, the flow of scrap rubber to reclaiming plants has greatly diminished. It must be started again. Every American must see to it that every ounce of old rubber he owns gets into war channels. Scrap rubber can be sold to junk dealers or can be given to charitable organizations. This is a tangible contribution that the American people can make to the war effort. Refusal to do so is hoarding at the expense of our armed forces.

GUAYULE

"The wild guayule shrub has been producing rubber for years in Mexico, and a small amount of cultivated guayule has been growing in the United States.

"A recent Act of Congress provided for the planting of 75,000 acres of guayule in the Western Hemisphere. Pursuant to this act, all available guayule seeds in the United States have been planted, and from these seedlings will come not only a harvest of rubber-bearing shrubs, but more seeds to increase the plantings. However, it will take four to six years to grow enough guayule rubber to make an appreciable contribution to the supply.

"Not more than 10,000 tons annually can be expected soon from Mexican guayule.

SOUTH AMERICA

"Negotiations are in progress with all Latin American countries, and agreements have recently been made with Brazil, Peru, and Nicaragua in which the United States will take the entire exportable surpluses of their rubber for the next five years. This will meet only a small part of our needs. Brazil will be able to ship this country from 10,000 to 15,000 tons of crude rubber this year, and, we hope, perhaps 25,000 to 30,000 tons in 1943. The Peruvian agreement is expected to provide between 6,000 and 10,000 tons over the five-year period.

"In 1912, Brazil produced over 40,000 tons of rubber. In recent years, however, the industry has deteriorated, and it will take considerable time to revive it. Most of the trees grow wild in the jungle, far from transportation facilities, and points of concentration are few and far between."

Resources Protection Board Established

A Resources Protection Board which will evaluate the relative wartime importance of all industrial plants, war installations, facilities, and vital economic resources and make recommendations for their protection was named recently by Donald M. Nelson, chairman of the War Production Board. William K. Frank of the production division of WPB was appointed to act as chairman of the new organization.

The Resources Protection Board will cooperate closely with the Army and Navy, the Maritime Commission, and Office of Civilian Defense in furnishing ratings and recommendations by which they may be guided in planning the protection of resources. It will make an over-all study of the relative importance to the war effort of all plants and installations, including factories, shipyards, railroads, communication networks, and mines and other natural resources. The hazards that will be considered will include bombing, sabotage, espionage, or actual invasion, as well as natural hazards such as fire and flood.

For over a year the Army, Navy and other agencies have been putting into effect protective measures. The new board will act as a co-ordinating agency to assure that no important resource or facility has been overlooked.

Goal of $12,000,000,000 Set for War Bonds in 1942–43

A letter signed by Secretary of the Treasury Henry Morgenthau, Jr., recently was circulated to thousands of business firms in the United States, pointing out clearly and frankly the situation the country faces in financing the war and describing a definite goal of war savings for everyone. *Electrical Engineering* has been asked to bring the contents of this letter to the attention of its readers; accordingly, the principal portion of the letter follows.

"Since the Defense Savings Program was launched in May 1941, events of far-reaching importance have occurred. To preserve our very existence we have been compelled to wage war upon far-flung battle lines. To maintain these lines, the President has said that during 1942 we must produce over 60,000 planes; 45,000 tanks; 20,000 antiaircraft guns; 8,000,000 tons of shipping; in addition to mobilizing, training, and equipping millions of fighting men. Upwards of 50 per cent of our total productive capacity and an equal share of our national income must be diverted to making war materials.

"This has meant a tremendous increase in the magnitude of the financial problem facing the Government. Reliable estimates indicate that during the next fiscal year (July 1, 1942 to June 30, 1943) we shall spend in the neighborhood of $60,000,000,000.

"The Revenue Act as it comes from Congress will determine how much of the money needed to finance the war is to be raised by taxation. The balance must be borrowed by the Treasury. In all probability, we shall have to borrow upwards of $35,000,000,000 between now and this time next year.

"If the Government is compelled to go to the commercial banks for the bulk of these funds, the result will be to increase inflationary tendencies which are already serious. This is true because when commercial banks buy Government bonds they do not pay for them with actual cash taken from their vaults, but by placing on their

books newly created deposits to the credit of the Government. When the Government draws upon these deposits to pay for the goods and services it buys, the purchasing power of those to whom these payments are made is increased without any decrease in the purchasing power of those from whom the money is borrowed.

"When bonds are purchased with savings out of current income, on the other hand, such savings help to reduce excess consumer income which if spent for a limited supply of consumer goods would tend to force prices up. It is for this reason, among others, that we are going directly to the people for as much as possible of the money needed for the war.

"It would be difficult to say exactly how much we can borrow directly from the people. We cannot, of course, hope to borrow in this way all that will be needed. Nevertheless, some definite objective is desirable if we are to have a standard by which to measure our success.

"We have, therefore, set as our goal for the twelve month period beginning July 1, the sale of United States Savings Bonds, Series *E*, *F*, and *G*, having an initial cost value of not less than $12,000,000,000. This will be equal to slightly more than 10 per cent of our estimated national income during this period.

"Sales of Defense Bonds during the period from May 1941 through March 1942 amounted to $4,860,000,000, or an average of approximately $440,000,000 per month. If we are to reach our goal—an average of a billion dollars a month—we shall have to increase this rate of sale by approximately 2½ times. This should not be difficult to do in view of the rapidly increasing national income and in view also of the fact that the supply of many commodities upon which people would normally spend their income will be restricted by the demands of war production.

"The seeing of a definite goal or quota does not mean an abandonment or basic change in our fundamental objectives and methods. It does mean an intensification of activity all along the line. It does mean that henceforth our savings campaign must move on a war basis. If we are to achieve the goal outlined for the nation as a whole, it will be necessary to establish subsidiary goals or quotas for states and counties. This we intend to do.

"The most effective, single method for promoting the systematic purchase of United States Saving Bonds is through the payroll savings plan. Already nearly 50,000 firms in the United States employing a total of almost 20,000,000 people have made such plans available to their employees.

TIME IS SHORT

"The ever increasing demands of our war machine create an urgency that we cannot escape or evade. To raise the billions we now need to win the war, and to do all in our power to check inflation, we must raise our sights. I am suggesting, therefore, as a total or quota for those administering the payroll savings plan, that at least 10 per cent of gross payroll be set aside by the employees for the purchase of United States Savings Bonds.

"We are still a long way from that goal. Among the nearly 50,000 firms having a payroll savings plan the average participation at the present time is about 45 per cent of the employees. The average monthly saving is about $7.50 per capita, representing in the neighborhood of 4.8 per cent of the pay of those participating. In other words, if we consider *all* of the employees of all the participating firms, only a bit more than 2 per cent of the gross payroll is now being invested in Defense Bonds.

"Considering the difficulties involved in the initial installation of payroll savings plans this is a good record. But we must go forward now on two fronts: First, we must increase the percentage of employees participating in payroll savings plans from approximately 45 per cent to at least 90 per cent of the total number. Second, we must encourage all participating employees to increase their average monthly allotment from about $7.50 per capita to an average of nearly $20 per capita."

EDUCATION • • •

Technological Institute Dedicated at Northwestern University

Dedication ceremonies for the newly completed $5,000,000 building of the Technological Institute of Northwestern University, Evanston, Ill., were held June 15–16, 1942. In addition to the dedicatory convocation on the afternoon of June 16, the program included three conference sessions, inspection tours, a dinner, and a reception. Distinguished representatives of government, education, and industry addressed the various sessions.

Sculpture and stonework around the main entrance of the building of Northwestern Technological Institute, Evanston, Ill., depict symbolically the background of technology. Over the left doorway Archimedes demonstrates the lever principle; over the right, Lavoisier studies combustion.

The electrical machinery laboratory, one of 20 laboratories in the electrical-engineering wing of Northwestern Technological Institute, contains a-c and d-c equipment and accessories.

Future Meetings of Other Societies

American Institute of Mining and Metallurgical Engineers. Regional meeting, October 12–17, 1942, Los Angeles, Calif.; joint meeting, coal division, AIME, and fuel division, ASME, October 1–2, 1942, St. Louis, Mo.

American Physical Society. 250th meeting, July 11, 1942, Berkeley, Calif.

American Welding Society. 23d annual meeting, October 12–15, 1942, Detroit, Mich.

Association of Iron and Steel Engineers. Annual convention, September 22–24, 1942, Pittsburgh, Pa.

Founded in 1939 by the gift of Walter P. Murphy, chairman, Standard Railway Equipment Manufacturing Company, the Technological Institute is headed by Ovid W. Eshbach (F'37) as dean. Its curriculum consists of four major departments, civil, mechanical, chemical, and electrical engineering, and is conducted on the co-operative plan developed by the late Dean Herman Schneider of the University of Cincinnati, under which students alternate periods of study of work in industry.

The new building of the Technological Institute, which houses all departments, is 500 feet wide and 342 feet deep, containing about 10 acres of floor space. It consists of a central structure containing the main auditorium, lecture rooms, library, student lounge, and main offices; and six wings, housing the four engineering departments of the Institute and the departments of physics and chemistry of the College of Liberal Arts.

Speakers at the dedication ceremonies included Director Donald M. Nelson, and Lieutenant General W. S. Knudsen of the War Production Board; Secretary of Commerce Jesse H. Jones; Raymond Walters, president, University of Cincinnati; Karl T. Compton (F'31) president, Massachusetts Institute of Technology; Martin W. Clement, president, Pennsylvania Railroad; Alex D. Bailey, chief operating engineer, Commonwealth Edison Company; Charles F. Kettering (F'14) president, General Motors Research Corporation; W. F. G. Swann, director, Bartol Research Foundation; George O. Curme, Jr., vice-president, Carbide and Carbon Chemical Corporation. Also participating in the ceremonies were Governor Dwight H. Green of Illinois; Alfred H. White, president, Society for Promotion of Engineering Education; Roger Adams, chairman of the department of chemistry, University of Illinois; Henry T. Heald, president, Illinois Institute of Technology; Robert C. Disque, acting president, Drexel Institute of Technology; Captain Frank Lash, Chaplain Corps, United States Navy; the Reverend Ernest F. Tittle, Evanston, Ill., as well as Franklyn Snyder, president of Northwestern University; Kenneth F. Burgess, president of the University's board of trustees; Dean Eshbach; and Walter J. Cummings, chairman of the board, Continental Illinois National Bank and Trust Company, who headed the dedicatory committee.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

A Peace Worth Fighting For

To the Editor:

President William E. Wickenden's address on "A Peace Worth Fighting For" (*EE, Mar. '42, p. 113–19*) is a most excellent and eloquent analysis of the economic problems that will confront the United States at the conclusion of the present world-wide social and economic cataclysm. That the conditions to be faced by the peoples now at war will try men's souls is self-evident. A realist might legitimately conclude that social and economic chaos will be the inevitable lot of the human race after, not the revolution, but the devolution of its spiritual and social values now taking place.

I can wholeheartedly agree with Doctor Wickenden in his contention that in production alone will rest the economic salvation of the world; and that, unless the United States too is prostrate, it must contribute to the reconstruction and regeneration of the countries devastated by war. But the inevitable economic prostration of most if not all of the world is not the only problem that will have to be solved. Other problems of even greater significance and influence will confront the statesmen, humanitarians, and all the peoples in whom there will still remain a slight spark of the spirit of the lowly Nazarene.

If I read Doctor Wickenden's thesis aright, his conclusions are based on the assumption that the failure of the United States to join the League of Nations, the "flood of destructive nationalism," and economic dislocations are the major causes of this war.

That these factors are, if not the real causes, the alleged causes no one will deny. But there are other and more basic causes that are seldom mentioned. But before discussing these, I would like to point out briefly that the League was planned for a democratic world. When the member nations ceased to be democracies the League had to die.[1] No nation could be compelled to be a democracy against its will, and hence the League, with or without the membership of the United States, was bound to be ineffective. The current assumption that our membership would have given vitality to the League is a mere allegation without any supporting evidence. Lord Kemsley does not ascribe the war to the failure of the League but to President Wilson's 14 points. His exact words are: "Who was responsible for the drawing up of the 14 points which ultimately brought about the second great war?"

No engineer should quarrel with the spirit of nationalism. If the Versailles treaty "let loose a flood of nationalism," that spirit was a reality presing for release. This spirit of nationalism was most strongly manifest by the small nations for they were the most cruelly oppressed. But none of these can be held responsible for the present holocaust. In short, the spirit of nationalism *is* a reality as much as the resistance of a conductor, and it can be neither exorcised nor suppressed. It must, therefore, be an important consideration in any future treaty of peace.

The more basic cause of the war mentioned above is the decay of the integrity of human beings and of their governments. 'Tis true that faith is the basis of civilization and in fact, of all human relations, but when that faith is destroyed reversion to barbarism and chaos is inevitable. Doctor Wickenden says we must have faith, and then asks, "faith in what?" Yes, faith in what! The maintenance of faith in our ability to weather the oncoming economic storm is easy in comparison with its restoration in the promises and pledged words of the Axis powers and their peoples. The present attack is not merely on the economic stability of the country, but upon its moral stability. It is the restoration and preservation of faith in moral values "that will try men's souls." A reincarnation of the forces of evil is, Samson-like, destroying the temple of civilization.

During the past 80 years Germany has initiated, or been principally responsible for five wars; against Denmark and Austria in the 1860's, against France in 1870, the war of 1914, and the present war.[2] The fundamental causes of all these wars were not economic but psychological. The psychological factors as they apply to the present war may be summed up in the words of Raoul De Roussy De Sales as follows:

"The combination of German military dogmatism and of the fanatical exaltation of the Nazi whirling dervishes is the overwhelming force which dominates the German soul today. The outside world must realize that, under such a regime, it matters very little whether Fritz and Hans are kind, humane, appreciative of the higher values of life, and in general civilized. All these tendencies are combated by the surroundings in which they live. The highest entity in which they are asked to believe and to which they belong, the German *Volk*, is presented to them as a negation of these values, as a great force

of destruction." And further he says: "The removal of Hitler might plunge Germany into chaos. It might end the war. It would not solve the German problem, because the roots of Hitlerism go far deeper than the immediate events which seem to have given it birth. Hitler is merely an accident in the evolution of Germany."[3]

The purpose of this war is not to give equal and like economic opportunities to all the peoples of the earth. Such an achievement is beyond the ability and power of any nation or combination of nations. The real objective is to quell a Germanic revolt against 2,000 years of civilization. That objective transcends all other forms of "peace worth fighting for" and its achievement will be most difficult. Nevertheless, it is the objective for which the people will dedicate and sacrifice their all.

Military victory will not of itself solve the problem of German revolt against the world. That solution can only come through the transformation of the German outlook on all the essential questions that for so many centuries have faced humanity. Before a permanent peace can be maintained, Germany must surrender its belief in the theory of racial superiority, and of the divine right of the German *Volk* to rule all other people. It must not continue as a chronic rebel in a democratic world, for if it does, the world will cease to be democratic and become militaristic.

REFERENCES

1. Democracy Today and Tomorrow, **Eduard Benes.**

2. Failure of a Mission, **Nevile Henderson.**

3. What Makes a German, **Raoul De Roussy De Sales.** *The Atlantic Monthly*, March 1942.

C. M. JANSKY (F'32)

(Professor emeritus of electrical engineering, University of Wisconsin, Madison)

An Analytic Approach to the Hysteresis Loop

To the Editor:

In the solution of most electrical engineering problems having to do with machine and transformer operation, it is essential to take into account the saturation of the iron circuit over the complete cycle of current and voltage. Solutions to this nonlinear problem have always been approximations, which, it must be granted, have been very faithful as to the actual performance of the apparatus.

The differential analyzer in the Moore School of Electrical Engineering at the University of Pennsylvania, Philadelphia, is often employed in the solution of such problems. When so used the accepted practice has been to omit the hysteresis effect of the iron and to consider only the normal magnetization curve as shown in Figure 1.

A somewhat unusual method for an approximation to the complete hysteresis loop may be arrived at through the use of the error function. So far as the authors know, no papers have been published in which this approximation was made. Under the proposed method, the hysteresis loop may be considered to be symmetrical about the normal magnetization curve. This would mean that one side of the loop is like the other except for a horizontal shift along the axis. The true curve, on the other hand, not only is shifted, but also is turned through 180 degrees about the X axis.

The hysteresis loop was approximated by the expression

$$B = B_s \operatorname{erf} \frac{H \pm H_c}{H_c} \qquad (1)$$

where

B_s = saturation value of flux density

H_c = coercive force

The sign of the H_c in equation 1 is plus when H is decreasing, and minus when H is increasing. For various kinds of iron H_c will vary. The introduction of H_c and the variation of H_c for various kinds of iron are taken care of on the differential analyzer through the use of a "dead-band" unit.

The dead-band unit is a device for the mechanical coupling of two linear shafts, one considered the driving shaft and the other the driven shaft. When the unit is inoperative, the driving shaft and the driven shaft act as a single coupled shaft. When the driving shaft starts to reverse, however, the driven shaft remains motionless for a preset number of turns of the driving shaft, at which time the two shafts again couple and act as a single shaft. In this particular case the driving shaft is H. The dead-band unit is set so that the driven shaft is still for H_c turns of the driving shaft. The output of the unit is then $H \pm H_c$, the quantity used in the error function.

Through an appropriate substitution of variables, it can be shown that the relation between B and H of equation 1 reduces to

$$-\frac{2}{H_s}\int (H \pm H_c)\,dB = \frac{dB}{dH} \qquad (2)$$

Equation 2 is in a form which the differ-

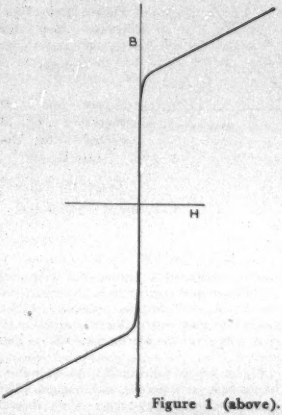


Figure 1 (above). Normal magnetization curve of sample of iron used in current relays

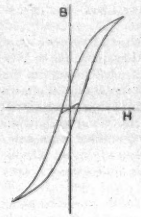


Figure 2 (left). Hysteresis loop as drawn by the differential analyzer. This is a solution of equation 2

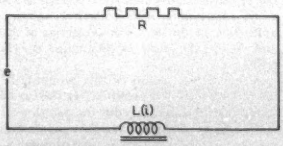


Figure 3 (above). Simple R–L circuit given by equation 4

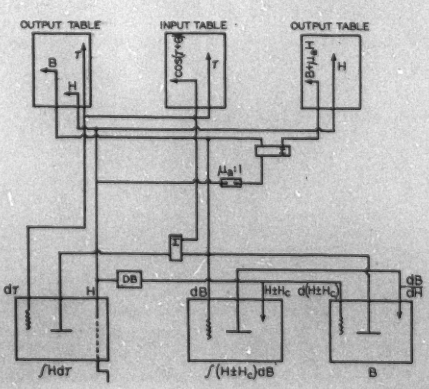
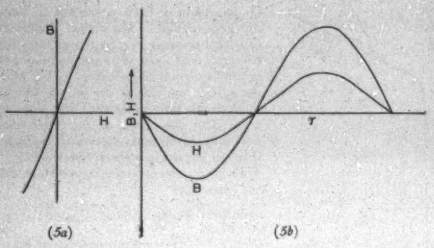


Figure 4 (right). Set up of differential analyzer for the solution of the nonlinear circuit shown in Figure 3, after the equation has been transformed to that given by equation 5



(5a) (5b)

Figure 5a. Hysteresis loop for $H_c = 0$ (no hysteresis)

Figure 5b. B versus τ and H versus τ for the case $H_c = 0$

ential analyzer can solve. A typical curve of B versus H is shown in Figure 2, which, it must be admitted, is not a bad first approximation to the actual curve. In order to take care of the tilt of the hysteresis loop a linear term of the form $\mu_a H$ was added to the flux density when the loop was plotted. Here μ_a is the permeability of air. The plotted curve shown in Figure 2 is then of the form

$$B = B_s \operatorname{erf} \frac{H \pm H_c}{H_s} + \mu_a H \qquad (3)$$

As an application of this method, solutions were obtained for the nonlinear circuit containing resistance and a saturable inductor (Figure 3). The equation to be solved here is

$$R_1 + 10^{-8} A \frac{dB}{dt} = E \sin \omega t \qquad (4)$$

Upon a change of variable, this equation becomes

$$\int H_d\tau + B = \cos(\tau + \theta) \qquad (5)$$

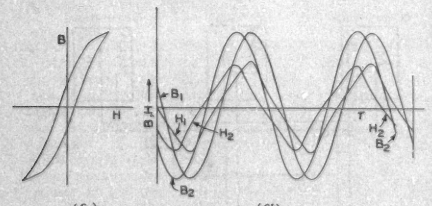
To solve this equation, considering the nonlinearity introduced by the B–H loop, the analyzer was set up as shown in Figure 4. The H shaft was turned by an operator in such a way as to maintain the relationship defined by equation 5. Typical results using various sets of parameters are shown in Figures 5, 6, and 7. Here B and H are plotted as functions of time τ, as well as a function of one another to produce the hysteresis loop. From the relationship between the magnetizing force and the current, the latter may be obtained from the curves.

Figure 5 is the case for $H_c = 0$. This corresponds to no hysteresis, and it is seen that since saturation was not reached, the B and H curves are sinusoidal in form. A steady state of operation is reached after a few cycles.

Figure 6 shows the case for another set of parameters, with dead band equal to 31.8 units, and H_c equal to 3.98 units on the plotted curve. Again the B and H curves are plotted as functions of time, and are almost sinusoidal, with the H curve showing some tendency toward a third harmonic. The curves labeled H_2 and B_2 are simply continuations along the time axis of curves H_1 and B_1.

Figure 7 is the case for an initial value of $dB/dH = 15$, with the applied voltage equal to one half the previous values. Here again the H curves show a definite tendency toward a harmonic, with a similar tendency appearing in the B. The meanings of H_2 and B_2 are the same as mentioned previously.

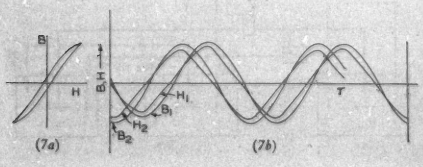
Although the results of this preliminary investigation show a possibility of the use of the differential analyzer for the plotting of B–H curves and their use in nonlinear problems, there still remains the problem of correlating the machine results with an actual sample of iron; that is, correlating the scale factors of the machine with the actual numerical values of B and H.



(6a) (6b)

Figure 6a. Hysteresis loop for $H_c = 3.98$, "dead band" DB = 31.8 units

Figure 6b. B versus τ, H versus τ for $H_c = 3.98$, DB = 31.8 units



(7a) (7b)

Figure 7a. Hysteresis loop for dB/dH = 15, but applied voltage is one half that for Figure 6

Figure 7b. B versus τ, H versus τ for same conditions

C. N. WEYGANDT (A'37) and S. CHARP

(Respectively assistant professor of electrical engineering and research assistant in electrical engineering, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.)

Use of Loud-Speaker Fields As Filter Chokes

To the Editor:

Since the use of loud-speaker fields as filter chokes is so common in radio these days, certain limitations to this system of field excitation should be pointed out. As is generally known, it is necessary to supply a "hum-bucking" coil in series with the voice coil to eliminate induced hum in the cone motion of the loud-speaker. It is not generally known, however, that this practice introduces relatively large amounts of distortion.

Let us consider the equation of motion of a loud-speaker. For the purpose of analysis, we shall neglect the inductance and the resistance of the voice-coil winding by considering what happens on the application of a given amount of current to this winding. Then the equation of motion is

$$I \frac{d^2x}{dt^2} + R \frac{dx}{dt} + kx = CBi$$

where

I is the inertia of the cone
x is the displacement of the cone
R is the frictional coefficient of the cone
k is the elastic constant of the cone
C is an arbitrary constant
B is the field flux density
i is the current in the voice coil

For the present discussion, we need consider only the right-hand half of the equation, namely CBi. We know that the frequencies of forced vibration are determined here, whereas the transient solutions are determined by equating the left-hand side to zero. Hence we wish to find out the frequencies of vibration established by the right-hand side. Let us take the flux B as of the following form:

$$B = B_0 + B_1 \sin 2x\mu t + B_2 \sin 4x\mu t + \ldots$$

The second, third, etc., terms on the right are the terms which the choke is attempting to eliminate. Let us take

$$i = i_0 \sin 2x\omega t$$

Then we find that CBi takes the form

$$C[B_0 + B_1 \sin 2x\mu t + \ldots] i_0 \sin 2x\omega t$$

This reduces to the form

$$CBi_0 \sin 2x\omega t + CB_1 i_0 \sin 2x\mu t \sin 2x\omega t + \ldots$$

The second term of this reduces to the form

$$\tfrac{1}{2}[\cos 2x(\omega - \mu)t - \cos 2x(\omega + \mu)t]$$

Hence, we notice that a ripple of magnitude B_1 will cause cross products of a magnitude $^1/_2B_1$. The hum-bucking coil eliminates the induced hum, but since it does not eliminate the variation in B, it does not remove the cross products. The total percentage of first order cross products will be $100B_1/B_0$. These cross products are very easily noticed in good equipment. Just a very small percentage of them will cause a noticeable blurring of the tonal reproduction of any radio or phonograph. Hence this effect is very important for the proper operation of any good loud-speaker. An absolute minimum of variation of the current exciting the field of the speaker is obviously necessary. Since variation of current is inherently present in the choking operation, use of the speaker field as a choke is not warranted if quality of reproduction is of primary importance. Only well-filtered direct current should be used.

KEATS A. PULLEN, JR. (Enrolled Student)

(Graduate school of engineering, The Johns Hopkins University, Baltimore, Md.)

Progress in the Art of Metering Electric Energy

To the Editor:

As you were so kind as to acknowledge the Long-Schattner prepayment meter (*EE, Jan. '42, p. 63*), I take this opportunity of sending you a photograph of the Atkinson-Schattner maximum-demand indicator, together with the official Board of Trade notice concerning it. L. S. Atkinson was recently president of the Institution of Electrical Engineers of Great Britain, and was a colleague of mine.

E. SCHATTNER (M'18)

(Consulting electrical engineer, London, England)

Field Testing of Generator Insulation

To the Editor:

The report of the EEI subject committee on "Field Testing of Generator Insulation" in the December 1941 section of AIEE *Transactions*, pages 1003–11, is outstanding in its excellent handling of a difficult subject and has given considerable impetus to the subject.

After close study of this report and related papers, it appears that an important truth may have been missed. If the initial and the two-year-old curves of Figure 3 on page 1005 are replotted as dielectric absorption curves upon Figure 1, page 1004, using the 60 degree centigrade temperature, it will be seen that the initial curve for 1938 is below that taken two years later in 1940 and is, therefore, the moister of these two curves. It is fairly well established that a difference in these slopes is an index of moisture, and it seems entirely rational to believe that moisture must have been driven off in the first two years of relatively high load, in addition to that remaining after the initial dryout run in 1938. While differences in volatile matter, aging, or curing may have some influence on the slope of the curves, it is easier to believe that change in moisture content has caused the major part of the change in these curves.

The slope of the dielectric absorption curve as an index of moisture has had startling confirmation in one 3,000-kva 2,300-volt generator winding measured by me, first, in clear dry weather with a dry Class A winding at 68 degrees centigrade after 27 hours at full load. The dielectric absorption curve rose steeply during five-minutes application at 1,000 volts to a final resistance of 150 megohms. The same winding was measured similarly after standing idle without heat for two days during cold, rainy weather, and with a final winding temperature of 16 degrees centigrade. This cold winding should have measured much higher than 150 megohms according to the well-known temperature effect, but the moisture effect completely obscured the temperature effect. Instead of a higher upward positive slope as expected, the readings began at 4 megohms and progressed downward in a negative slope and leveled off after about 12 minutes to 1.25 megohms. In no reports I have read has there been any mention of the possibility of this slope turning downward, and this seems to be new information. There was considerable apprehension felt as to the safety of returning this generator to full voltage service without dryout, although the generator had been off line only two days. However, the generator was brought up to full voltage successfully in four increments of voltage, the open-circuit core loss and windage furnishing some heat and ventilation. Our practice 20 years ago would probably have been to throw the generator on line with no thought of moisture content. We

EXTRACT FROM

The London Gazette

OF

FRIDAY, JULY 10, 1903.

Board of Trade, 7, Whitehall Gardens, London, July 9, 1903.

H. 9899.

For the purposes of the Electric Lighting Acts, 1882 and 1888, and of the Electric Lighting (Scotland) Act, 1890, and all Provisional Orders and Licences made and issued thereunder, the Board of Trade approve of the pattern and construction of the indicator (hereinafter described) for the measurement of electrical quantity when supplied on the constant potential continuous or alternating current system, namely :—

The Atkinson Schattner Maximum Demand Indicator deposited at the Board of Trade on the 3rd of June, 1903, by or on behalf of the Schattner Electricity Meter Company Limited, London, and sealed by the Board of Trade and known as the Atkinson Schattner Maximum Demand Indicator.

Provided that the indicator be tested, fixed, and used as described in the specification and instructions deposited at the Board of Trade and dated and numbered 19th June, 1903, and H. 9899.

The Board of Trade further approve of the means provided for fixing indicators of this description, and for connecting them with the service lines as described in the specification and instructions above referred to.

Signed by order of the Board of Trade this 9th day of July, 1903.

T. H. W. Pelham, Assistant Secretary, Board of Trade.

Figure 1 (left). Facsimile of notice by the London Board of Trade approving the use of the Atkinson-Schattner maximum-demand indicator

Figure 2. Atkinson-Schattner maximum-demand indicator, 1903 (Science Museum, South Kensington, London, England)

need more information of this type to show how much latitude it is safe to take in such a case.

If my belief is correct, that Figure 3 and Figure 1 both show moisture content, it follows that the constant "M" which expresses the slope in Figure 3 might very well be used as a standard numerical index and called "moisture slope M."

A study of Figure 3 will show that in comparing the 15-second readings of curves E and J whose slopes are $M = 1/38$ and $1/34$, the difference in slope is too small to be a decisive moisture index and curves A and F after 10 minutes would be much better. Also, if the megohm readings at 40 degrees centigrade of the upper group of curves representing a slightly moist insulation, are compared to the lower curves representing very dry insulation, the difference is small compared to the large spread if the 75-degree centigrade temperature is used instead. It would, therefore, be a happy solution to use the 10-minute points of the dielectric absorption curves for temperatures as near as feasible to 75 degrees centigrade and 40 degrees centigrade to obtain a "standardized moisture slope M," which may completely represent the moisture condition, if properly made, recorded, and used for comparison purposes. I propose to inaugurate this idea for standard comparisons between the various generators operated by the United States Bureau of Reclamation in the hope it will yield some valuable information.

H. H. PLUMB (M'29)

(Senior engineer, in charge of power-system operation and maintenance, United States Bureau of Reclamation, Denver Colo.)

NEW BOOKS • • •

Acoustic Design Charts. By Frank Massa. The Blakiston Company, Philadelphia, Pa., 1942. 228 pages, charts, etc., $4.

This book converts basic acoustic theory into a series of 107 practical charts of quantitative value which may be used without laborious computations and interpretations. The scales used have been chosen with a view to obtaining constant precision in reading the large range of values plotted. Families of curves on many of the charts reveal the quantitative effect of varying the parameters of a system. Sample problems have been worked out to illustrate the use of each chart. The subject matter includes the design of acoustic, mechanical, and electroacoustic apparatus, vibrating mechanical systems, isolation of machinery, noise reduction, electromagnetic and permanent magnet design, electric circuit, and other data.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

These and thousands of other technical books may be borrowed from the library by mail by AIEE members.

Diesel Engineering Handbook, Volume 2. Edited by L. H. Morrison. Diesel Publications, New York, 1941. 574 pages, illustrated, 9½ by 6 inches, cloth, $5.

Intended to supplement previous editions. The material contained is either entirely new or an amplification of topics already considered. Engine efficiencies, specifications, special installations, and various types of auxiliary equipment not previously covered are discussed.

Marine Electrical Installation. By J. F. Piper. Cornell Maritime Press, New York, 1941. 308 pages, illustrations, etc., 7½ by 5 inches, cloth, $2.50.

This manual is intended to aid the inexperienced workman to obtain practical insight into electrical marine work. The tools and materials used, the laying out of work, wiring methods, and power, lighting and communication systems are described in detail without undue use of technical language.

How Your Business Can Help Win the War. Compiled by the staff of industrial specialists of the Conover-Mast periodicals, edited by H. W. Barclay, with an introduction by D. M. Nelson. Simon and Schuster, New York, 1942. 111 pages, charts, etc., 11 by 8 inches, paper, $1.

Designed to show business men what the government wants to buy, how to bid, and how to get contracts and sub-contracts for government orders, it also indicates ways in which time and money can be saved and red tape cut in dealing with government offices.

Electrical Illumination. By J. O. Kraehenbuehl. John Wiley and Sons, New York, 1942. 441 pages, illustrations, etc., 9 by 6 inches, cloth, $3.75.

The principles underlying the specification and design of electric lighting for commercial and industrial buildings are presented as an elementary course for architectural and electrical engineering students. Maintenance and economic factors are discussed, and there are special chapters on floodlighting and novelty lighting. A bibliography accompanies each chapter.

University Physics, Part III, Light. By F. C. Champion. Interscience Publishers, New York, Blackie and Son Limited, London and Glasgow, 1941. 172 pages, diagrams, etc., 9 by 6 inches, cloth, $1.50.

One of a group of books on the several major divisions of physics, this volume aims to cover the subject of light for intermediate students who have previously studied the elements of physics. Exercises and problems are supplied for review purposes.

University Physics, Part IV, Wave-Motion and Sound. By F. C. Champion. Interscience Publishers, New York, Blackie and Son Limited, London and Glasgow, 1941. 67 pages, diagrams, etc., 9 by 6 inches, cloth, $1.65.

Attempts to cover the fundamental properties of wave motion, the propagation, characteristics and detection of sound, the vibration of solid bodies, and a brief discussion of acoustics. Exercises and problems are included.

Problems and Policies in Industrial Relations in a War Economy. Selected References, Fourth Supplement, January 2, 1942, Bibliographical Series No. 66. Princeton University, Industrial Relations Section, Princeton, New Jersey, 1942. 27 pages, 9 by 6 inches, paper, 25 cents.

Covering both American and foreign subject matter, the items listed in this supplement deal with problems and policies related to various phases of the labor question as they occur under war conditions, including employee training, hours, wages, housing, and legislation.

Horizons Unlimited, a Graphic History of Aviation. By S. P. Johnston. Duell, Sloan and Pearce, New York, 1941. 354 pages, illustrated, 10 by 6½ inches, cloth, $3.75.

The story of man's conquest of the air is presented, and the social consequences of the development of the means of flight are considered. Brief discussions of meteorology and aerodynamics are also included.

Television, Today and Tomorrow. By L. de Forest. The Dial Press, New York, 1942. 361 pages, diagrams, etc., 9½ by 6 inches, cloth, $3.75.

In this book the history of television is briefly recounted, how and why it works are demonstrated, and the functioning of a present-day studio is described. Television as a profession is discussed, as well as the probable future of television and its influence upon society.

General Trade Mathematics. By E. P. Van Leuven. McGraw-Hill Book Company, Whittlesey House, New York, 1942. 575 pages, illustrations, etc., 9½ by 6 inches, cloth, $3.50.

The mathematics needed to solve actual shop problems in manufacturing and mechanical operations is presented for practical use. Beginning with arithmetical operations, the material includes simple algebra and geometry and specific industrial calculations. Practical problems are also furnished.

Fluorescent Lighting Manual. By C. L. Amick. McGraw-Hill Book Company, New York and London, 1942. 312 pages, illustrations, etc., 9½ by 6 inches, cloth, $3.

Intended to provide information on the construction and performance of all types of fluorescent lamps. Principles and methods of calculating illuminating requirements and designing luminaires are given as well as methods and special pointers for installation and maintenance. A comparison of the economic factors of fluorescent and incandescent lighting is also included.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the December 1942 Supplement to Electrical Engineering—Transactions Section

Thermal Co-ordination of Motors, Control, and Their Branch Circuits on Power Supplies of 600 Volts and Less

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ASSOCIATE AIEE

THE protection of a motor against an overload or the protection of a motor and its branch circuit against a short circuit are basically the same problem. The entire circuit is heated at a rate which is a function of the amount of current flowing, and this current must be interrupted before the winding or any part of the circuit exceeds a prescribed temperature. The means used to protect against these two magnitudes of power may be the same, or it may be entirely different as will be brought out later. It is the purpose of this article to show what the heating characteristics are of the motors, the control, and the branch circuit wiring, and what the characteristics of the protective devices should be in order that the power will be disconnected from the main feeders under all conditions of excess current before excess temperatures are attained.

The points which this article will discuss and some of the conclusions reached are:

1. That the short-time heating characteristic of three-phase induction motors stators can be shown in a simple graphical method when we know the current density in the stator windings at rated current. These data should then be used as the basis for determining the tripping characteristic of overload and short-circuit protective devices.

Paper 42-79, recommended by the AIEE committee on industrial power applications for presentation at the AIEE North Eastern District meeting, Schenectady, N. Y., April 29–May 1, 1942. Manuscript submitted February 16, 1942; made available for printing March 30, 1942.

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2. If the cross section of the reduced section of a zinc fuse link is not greater than any part of the copper conductors nor greater than 45 per cent of any Nichrome conductor (the heaters of overload relays), then the fuse will give good short-circuit protection to the copper and to the Nichrome conductors.

3. Small horsepower starters, which are within the range of from 1 to 50 horsepower at 440 or 550 volts, or of 1 to 25 horsepower at 220 volts (classified as National Electrical Manufacturers' Association size 3 or smaller), require a short-circuit protective device that will interrupt the circuit during a heavy short circuit in less time than one-half cycle. Tests have shown that a suitable size nonrenewable cartridge-type fuse of good design is capable of doing this.

4. Because of this fast interrupting ability, this type of fuse is current-limiting (see Figures 6 and 7). Therefore, it gives two-way protection, in that it both limits the amount of current which reaches the starters, and it is exceptionally fast when the currents are high.

5. Because of the inductance in a d-c generator, its current will build up at a slower rate during a short circuit than will the current in an a-c circuit, and therefore a fuse will be more current-limiting on a d-c system when supplied from a d-c generator than on an a-c system. Unlike the a-c power, the peak voltage and the average voltage is the same on d-c systems. Because of these two factors it is easier for a fuse to interrupt a short circuit on a d-c system than on an a-c system of the same rated voltage since the entire interrupting period takes place in a fraction of a half cycle.

6. A NEMA size 3 starter (50 horsepower at 440 volts or 550 volts, three phase) or smaller can be fully protected against any major damage from short circuits on a system having available currents up to 100,000 amperes, provided a correct current and voltage nonrenewable cartridge-type fuse of good design is placed in each branch circuit line, and provided the fuses are positively held in their clips so as to prevent magnetic forces from throwing them out.

7. A circuit breaker provided with a fast instantaneous magnetic trip, as used on our tests, demonstrated its ability to protect NEMA size 4 and larger starters, when on a system having an available current equal to or less than the interrupting rating of the breaker.

8. The maximum size fuse that should be used is $3^1/_2$ times the current rating of the overload relay, or four times the current rating of the motor, and if this does not result into the same current, then the smaller of the two should be selected. See Figure 3.

Permissible Temperatures

Let us first decide what are excess temperatures. Much has been written on this subject,[1] but it is quite generally agreed that 90 to 100 degrees centigrade is a satisfactory temperature (approximately 50 degrees rise), where it is maintained for long intervals, but where the temperatures are transient and last for only a few seconds or minutes and occur infrequently, then this 50 degrees rise can be materially increased. For conditions like a stalled squirrel-cage induction motor which lasts for only a few seconds the 50 degrees rise can be doubled. A rise of 100 degrees is satisfactory for a stalled motor because it will seldom be called upon to withstand this condition and then for only a few seconds.

Current-Time Heating Characteristics

Let us now ascertain the heating characteristic of a three-phase squirrel-cage type of induction motor. When a representative type of induction motor is running at rated load, approximately one third of its total heat loss will be produced by the iron, and the remaining two thirds will be produced by the copper. But if the motor is stalled and taking five times rated current, then the iron loss will re-

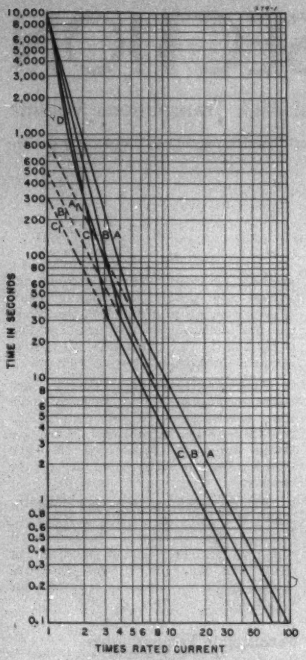

Figure 1. Heating characteristics of three-phase induction motors. Also tripping characteristics of a representative temperature overload relay

Curve *A*—Current-time curve for copper, showing rate of heating where current density is 3,000 amperes per square inch at rated current, and maximum temperature reached is 100 degrees centigrade rise

Curve *B*—Same as *A* except current density is 4,000 amperes per square inch

Curve *C*—Same as *A* except current density is 5,000 amperes per square inch

Curves A_1, B_1, C_1—Extensions of *A*, *B*, and *C* to show the rate of rise if there were no heat loss

Curve *D*—Current-time tripping curve of a high-grade temperature overload relay

Because of heat conduction into the insulation and into the iron of the motor, and because of convection from the motor, the temperature rise for times of 30 seconds and longer will range between 50 degrees centigrade minimum and something under 100 degrees centigrade maximum

main the same, but the copper loss will be 25 times larger. Under either a running or a stalled condition, the copper will lead the iron in temperature, but in the stalled condition will be leading so far that we can assume the iron temperature

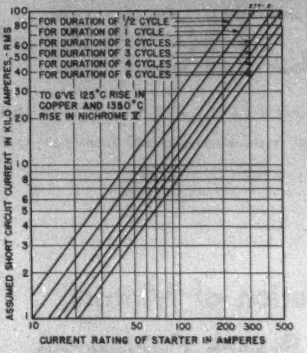
FOR DURATION OF 1/2 CYCLE
FOR DURATION OF 1 CYCLE
FOR DURATION OF 2 CYCLES
FOR DURATION OF 3 CYCLES
FOR DURATION OF 4 CYCLES
FOR DURATION OF 6 CYCLES
TO GIVE 125°C RISE IN COPPER AND 1350°C RISE IN NICHROME V
ASSUMED SHORT CIRCUIT CURRENT IN KILO AMPERES, RMS
CURRENT RATING OF STARTER IN AMPERES

Figure 2. Required interrupting speeds fully to protect starters having heater-type overload relays against specified short-circuit currents

will be stationary in temperature, while the copper is going its limit. The length of time required for the copper to go its limit of 100 degrees centigrade rise will depend upon the current density in the copper. Let us assume that the current densities in the stator copper of the standard lines of three-phase induction motors fall within 3,000 to 5,000 amperes per square inch when carrying their rated currents, then curves *A*, *B*, and *C* of Figure 1 show the time required for these three copper densities to reach 100 degrees rise for any current from 1 to 100 times their ratings. This is based on the assumption that all the heat remains in the copper, and none is conducted out into the insulation or iron, or carried off by convection or by radiation. For short circuits where the considered time is one second or less, this assumption is sufficiently correct, but for stalled conditions of the motor, or for heavy running overloads where the no-loss time required to reach 100 degrees rise is 30 seconds or more, there will be sufficient loss from the copper due to heat transfer that recognition should be made. Referring to Figure 1, it will be noted that at the 30-second position of the *A*, *B*, and *C* curves they have changed their current-time rate in order that this heat transfer can be approximately indicated in a simple diagrammatic manner. At the 30-second position, where the two curves diverge, we know that if no heat had escaped from the copper, it would have a 100 degrees rise, but we know that some heat has escaped during this 30 seconds, so the temperature will be below the 100 degrees rise (perhaps 85 or 90 degrees rise or less). Likewise, at the 10,000-second position, where the motor is carrying its rated load, the heat transfer has reached an equilib-

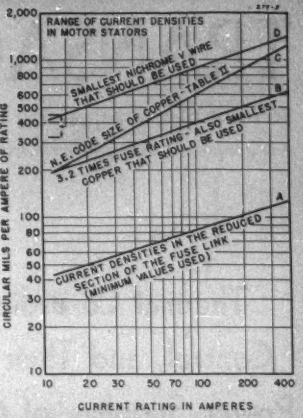
RANGE OF CURRENT DENSITIES IN MOTOR STATORS
SMALLEST NICHROME V WIRE THAT SHOULD BE USED
N.E. CODE SIZE OF COPPER - TABLE II
3.2 TIMES FUSE RATING - ALSO SMALLEST COPPER THAT SHOULD BE USED
CURRENT DENSITIES IN THE REDUCED SECTION OF THE FUSE LINK (MINIMUM VALUES USED)
CIRCULAR MILS PER AMPERE OF RATING
CURRENT RATING IN AMPERES

Figure 3. Current densities in copper and in Nichrome V wires, in stator windings of squirrel-cage three-phase induction motors, and in the restricted section of General Electric low-voltage cartridge-type fuses when carrying their respective rated currents

rium whereby the temperature rise on the copper is 50 degrees—the rated rise of the motor—therefore, along various positions of the *A*, *B*, and *C* curves between 30 and 10,000 seconds, the temperature rise gradually increases as the load increases, reaching something less than 100 degrees rise at a stalled condition.

Thus, by the use of log-log-paper a very simple graphical method can be used, wherein the well-known thermal capacity of copper and the assumed current density used in the motor design can be used as the basic factors in this graphical method. The resultant temperatures obtained in this simple manner will be sufficiently close for all practical purposes, and the temperatures will be on the conservative side. Therefore, the three straight lines in Figure 1 between 30 and 10,000 seconds, which are labeled *A*, *B*, and *C* can be used to closely represent the transient heating time-current characteristics of the stator of the three designs of motors which have the 3,000-, 4,000-, and 5,000-amperes per square inch densities in the copper when carrying their rated currents.

Required Temperature-Overload-Relay Characteristics

Thus, if these three time-current characteristic curves are used as the basis for designing three temperature overload relays such that the relay-tripping times never exceed those shown on these curves and yet keep fairly close to them, then these relays should be capable of protect-

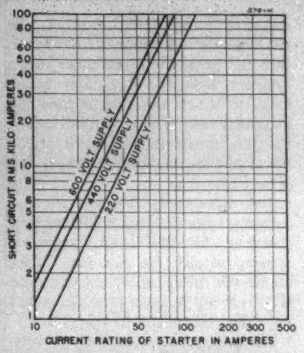

Figure 4. Magnitude of short-circuit currents for a circuit in which 20 volt-amperes per phase is assumed for the total impedence of the circuit when carrying rated current

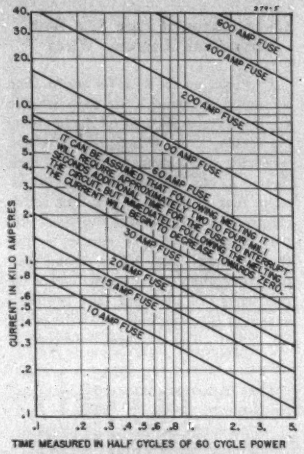
600 AMP FUSE
400 AMP FUSE
200 AMP FUSE
100 AMP FUSE
50 AMP FUSE
30 AMP FUSE
20 AMP FUSE
15 AMP FUSE
10 AMP FUSE
IT CAN BE ASSUMED THAT FOLLOWING MELTING IT WILL REQUIRE APPROXIMATELY TWO TO FOUR TIMES THE MELTING TIME FOR THE FUSE TO INTERRUPT THE CURRENT. THE RECOVERY VOLTAGE WILL DECREASE TOWARDS ZERO.
CURRENT IN KILO AMPERES
TIME MEASURED IN HALF CYCLES OF 60 CYCLE POWER

Figure 5. Time required for General Electric cartridge-type low-voltage fuse links (zinc) to melt

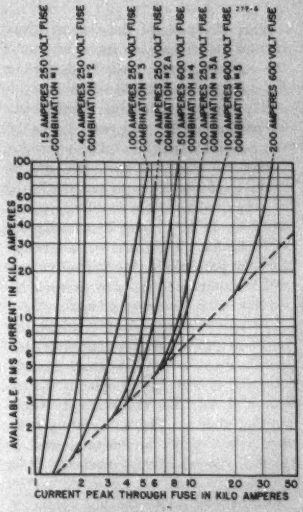
15 AMPERES 250 VOLT FUSE COMBINATION #1
40 AMPERES 250 VOLT FUSE COMBINATION #2
100 AMPERES 250 VOLT FUSE COMBINATION #3
40 AMPERES 250 VOLT FUSE COMBINATION #2A
50 AMPERES 600 VOLT FUSE COMBINATION #4
100 AMPERES 250 VOLT FUSE COMBINATION #3A
100 AMPERES 600 VOLT FUSE COMBINATION #5
200 AMPERES 600 VOLT FUSE
AVAILABLE RMS CURRENT IN KILO AMPERES
CURRENT PEAK THROUGH FUSE IN KILO AMPERES

Figure 6. Current-limiting characteristics of one standard nonrenewable cartridge fuse per phase on a three-phase power supply

Combinations 1, 2, 2A, 3, and 3A were tested on 440 volts, three-phase power. Combinations 4 and 5 were tested on 600 volts, three-phase power

Starter Combination	Ohms Impedance
1	0.252
2	0.157
2A	0.029
3	0.065
3A	0.015
4	0.048
5	0.018

ing the three designs of motors against all magnitudes of overloads and yet permit them to do their full quota of work. However, the heater type of temperature overload relay, which develops its source of heat in one element—its heater—and transfers this heat to the bimetal or temperature sensitive element, tends to slow down on the high-current end such that the relay-tripping characteristic curve would normally cross the motor-heating curve at the high-current end. This type of relay must, therefore, be sufficiently fast at the stalled current value—approximately six times current—to give the required protection, and then at the lower current values of overload it will overprotect the motor. But since this is the characteristic of the relay most commonly built for the smaller motors, it follows that if this design is so made that it is correct for the stalled condition of the motor, it will be somewhat faster than necessary for all the lower degrees of overloads. This degree of overprotection is not generally sufficient to interfere with the motor's doing its required work.

The total thermal capacity of a motor is a function of its copper, its insulation, and its iron, but under a stalled condition the *effective* thermal capacity of this same motor is primarily a function of only its copper. Thus the effective thermal capacity of a motor under all degrees of overloads is a variable, having about a four-to-one range. Therefore, if a relay is designed which has a duplicate heating characteristic to that of the motor, then it must also have an effective thermal capacity which is a variable. This of course complicates the problem and results in a larger and a more complicated relay. Such a design is available and has been supplied since 1924, but it is not a large production unit because of its size and cost. Unless this desired characteristic can be designed into a relay which is both inexpensive and small, I doubt whether the trade will need this variable thermal-capacity characteristic sufficiently to demand it. Large motors will always require the best designs available, but the control for small motors will be determined largely by cost. Therefore, the small and inexpensive heater type of thermal overload relays will very likely be continued for some time.

The above discussion regarding how we can protect the insulation of a motor by protecting it against excess temperatures should not lead us to conclude that, if we do a good job in this respect, no insulation troubles will occur. These troubles may develop as a result of transient voltages, faulty work, mechanical injury, or from many other causes. Therefore means should be provided which will give adequate fault protection to the branch circuit, the control devices, the motor, and to the operating personnel.

Short-Circuit Protection

The devices which provide the degree of overload protection just discussed will not, in general, provide the necessary protection to the branch circuit and to the control against short circuits. In our discussion we have assumed that ten times rated current is the dividing line between overload and short-circuit conditions. Above ten times current the effective thermal capacity will be proportional to the copper in the stator winding of the motor and in the branch circuit and the control. Also we have assumed that 100 degrees centigrade rise will be the upper limit of temperature for the stator copper under overload conditions, but for short-circuit conditions 100 degrees rise is somewhat low. We will, therefore, assume that the temperature rise may be 125 degrees—a very, very conservative value—and that the Figure 2 curves will show the necessary speed of interruption required to keep the copper within these limits. The 125 degrees rise (165 or 175 degrees total) is not the limit to which it is permissible to carry copper with its insulation, but, when wire is selected for its continuous current-carrying ability, its resultant temperature under short-circuit condition will be in accordance with the above assumptions.

Since the path of the current which reaches the motor must travel by way of the conductor cable and the devices on the control panel, it will be necessary to also consider the heating characteristic of these current-carrying parts during this short-circuit condition. The conductor cables and contactor parts, we will assume, are made of copper and the heater of the temperature overload relays, which are in most motor circuits, is made of Nichrome. Therefore, we can assume that the path of the short-circuit current will be through copper and through Nichrome of known cross sections.

To protect the conductors adequately in the branch circuit, the control devices, and the motor winding, we must use a device that is both fast in opening the circuit and also has the necessary interrupting ability. The temperature overload relay, which is generally used to protect a motor against overloads, is far too slow to assist in protecting against short circuits. Also the line contactor, connecting and disconnecting the motor to and from the line, does not generally have the necessary interrupting capacity, even if the temperature overload relay could assist it in opening sufficiently fast—as it cannot do—and so we must look for other means which can function sufficiently fast and have adequate interrupting ability.

The most common form of short-circuit protective means used on low-voltage lines is cartridge-type nonrenewable fuses and air-break circuit breakers. If we consider first the fuse then a third material, namely zinc of the fuse link, will be added in the path of the short circuit. We must, therefore, consider the correct relationship between the cross sections of the zinc fuse link, the copper, and the Nichrome heater so that neither the copper nor the Nichrome will exceed certain prescribed temperature rises. To do this we will assume that when the fuse melts, the copper will have reached 70 degrees centigrade rise, the Nichrome 800 degrees rise, this fuse-melting period being one unit of time. Following the melting of the fuse, the current will be reduced to zero in an additional time which we will assume to be two units of time (this has been shown by tests to be a conservative assumption), and the rms current value, during this fuse-arcing period, we will assume to be 58 per cent of the value existing at the instant of melting. During the fuse-arcing period the copper is assumed to have an additional rise of 55 degrees and the Nichrome a rise of 550 degrees, making a total rise of 125 degrees for copper and 1,350 degrees for Nichrome.

Co-ordination of Fuse Size With Copper and Nichrome Wires

In setting up the basis for our problem as shown in Figure 3, we have selected the largest cross sections on the fuses and the smallest cross sections on the copper wire sizes, which means that there is some margin in our basic figures. Let us assume that a copper, a zinc, and a Nichrome wire are connected in series and that a given value of current is put through them. Also let us assume that the cross sections of the copper and of the zinc wires are the same, but the cross section of the Nichrome wire is larger by 2.2 times. The average resistance of

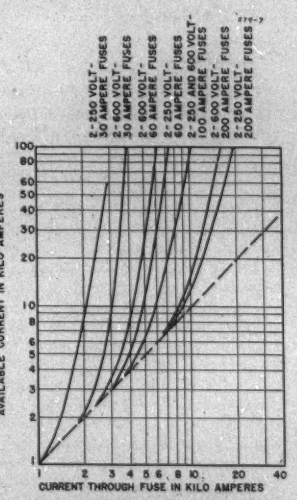
2-250 VOLT-30 AMPERE FUSES
2-600 VOLT-30 AMPERE FUSES
2-600 VOLT-60 AMPERE FUSES
2-250 VOLT-60 AMPERE FUSES
2-600 VOLT-100 AMPERE FUSES
2-600 VOLT-200 AMPERE FUSES
2-250 VOLT-200 AMPERE FUSES
AVAILABLE CURRENT IN KILO AMPERES
CURRENT THROUGH FUSE IN KILO AMPERES

Figure 7. Current-limiting characteristics of standard nonrenewable cartridge fuse on 250-volt d-c power

zinc per circular mil foot between 20 and 419 degrees centigrade (melting) is 69 ohms, while the average resistance of copper per circular mil foot between 20 and 70 degrees is 12 ohms. This makes the average resistance of zinc 5.75 times larger than copper. Therefore, when the copper reaches 70 degrees rise the zinc should be $70\times5.75=400$ degrees centigrade rise assuming no loss of heat. Since the Nichrome wire, which is 2.2 times larger in cross section, is carrying the same current, and since its average resistance is 670 ohms per circular mil foot, the Nichrome wire should have a rise of $70\times670/12\times(1/2.2)^2=800$ degrees centigrade.

Now, the above time is just sufficient to melt the fuse material; to raise the copper to 70 degrees centigrade rise; and the Nichrome to 800 degrees rise. At this time the current is a maximum, and a sufficient additional time must be allowed to reduce this current from this maximum value to zero. We will assume that this current reduces along a straight line so that the rms current is 58 per cent of the maximum.

Tests have shown that for very high currents, twice as much additional time should be allowed for interruption as was required to melt the zinc fuse. Then during this arcing period the rms value of current will be equal to 58 per cent of the value which melted it.

Therefore, if we initially allow a sufficient current to flow through the copper to cause it to reach a 70 degrees centigrade rise (from 20 degrees base) in a unit of time and then allow 53 per cent of this current to continue to flow for two units of time, the copper will have a 125 degrees total rise, because if a given current value flowing for one unit of time results in a 70 degrees rise, then 58 per cent of this current for two units of time will give $70\times(0.58)^2\times2\times1.17=55$ degrees centigrade rise. This rise of $55+70=125$ degrees centigrade. (The 1.17 represents the average increase of the copper resistance due to the higher temperature.)

And if this same 58 per cent value also went through the 220 per cent cross section of Nichrome, it would have an additional rise over its 800 degrees centigrade value of $(125-70)680/14\times(1/2.2)^2=550$ degrees centigrade or a total of $800+550=1,350$ degrees centigrade. (The 680/14 also represents the increased resistance due to the higher temperature.)

Therefore, from this line of reasoning, which has been checked by test, we can expect satisfactory results if we have a given cross section of the zinc fuse link—the reduced part of the fuse link—and then see that no part of the copper cross section is smaller than this fuse cross section, and also see that the Nichrome cross section is not smaller than 2.2 times the fuse cross section.

To obtain the above cross-sectional relationships, let us call the current rating of the motor as 100 per cent; then the current rating of the overload relay will be 115 per cent; the current rating of the branch circuit wiring as given in the 1940 National Electrical Code, Table II, chapter 10 will be 125 per cent; and the current rating of the fuse will be 400 per cent. Figure 3 shows graphically the current densities in these three materials. For example a 25-ampere control should have copper cross sections of $250\times25=6,250$ circular mils and Nichrome cross

sections of 550×25=13,750 circular mils as minimum cross sections while the maximum size fuse that should be used is 25×3.2=80 amperes, which should have the same cross section as the copper—6,250 circular mils. If the motor has a service factor of 1.15, then the motor rating would be 25 divided by 1.15=21.7 amperes.

Estimated Magnitude of Short-Circuit Current

It is frequently desirable to estimate the magnitude of short-circuit current that will pass through a given size starter, and then determine how long this current can be permitted to flow without exceeding the temperatures prescribed above. Figure 4 was developed on the basis of 20 volt-amperes per phase for the total impedance of the circuit when carrying rated current (this is an approximate minimum impedance generally found). This will hold fairly well for the smaller sizes of control (25 horsepower and less) where the impedance of the supply circuit is a small part, but for larger sizes of starters this method will show too large a value of current. But if an expected value of current is determined by this or other means, then Figure 2 will show how long this value of current can be permitted to flow and still keep the temperatures within the bounds set above, namely 125 degrees centigrade rise on the copper and 1,350 degrees rise on the Nichrome. For example, Figure 4 shows that for a 25-ampere starter at 600 volts the expected short-circuit current would be 10,000 amperes, while Figure 2 shows that a 25-ampere starter can withstand only 4,700 amperes for one one-half cycle or 3,300 amperes for one cycle of time duration. Therefore, since the heating varies as the square of the current this size of starter could carry 10,000 amperes for only $(0.47)^2$ (half cycle) or 0.00184 second. This is obviously faster speed than that of a circuit-breaker operation—which is in the order of 0.008 to 0.015 second—but as shown in Figure 3, a correctly selected fuse can do the job for any current because its time of operation will vary with the magnitude for the current.

Interrupting Speed of Fuses

Another pair of questions that are frequently asked is how fast will a fuse interrupt the circuit, and how much available energy can it interrupt? The first question must be divided into two parts in order that we might segregate the important factors, namely the length of time required to melt the link, and then the time required to interrupt the circuit. The time required to melt the link of General Electric nonrenewable fuses is shown in Figure 5, which gives the time in half cycles (60 cycles assumed). For a fuse to be current-limiting, it must melt in the early stages of a half cycle—such as one fourth of the half cycle—Figure 5 shows that a 100-ampere fuse of this type will melt in this time when approximately 10,000 amperes are put through, and Figure 6, which is a test record, shows that the available current may be around 10,000 amperes value. This means that the fuse stops the current from materially exceeding the value reached at melting. And of course, this effect becomes more pronounced on the smaller size fuses.

It is, therefore, obvious from Figures 5 and 6 that the degree of current-limiting becomes less and less as the size of fuses increases, and that for ordinary powered circuits the fuses larger than 200 amperes size do not give much current-limiting effects. It is also obvious that the 200-ampere fuse and smaller interrupt in one half cycle or less when subjected to currents of 10,000 to 20,000 amperes. This means that fuses do an exceptionally fast interrupting job in protecting motors and controllers of 100 horsepower (size 4 starters) and less.

Interrupting Ability of Fuses

The second half of the question dealing with the amount of available energy which these fuses can interrupt was determined by providing a 250-volt d-c source which was capable of delivering 96,000 amperes, and also a three-phase source which was capable of delivering an rms symmetrical current of 84,000 amperes at 440 volts and 114,000 amperes at 600 volts. In the d-c circuit was placed two standard nonrenewable General Electric 250-volt fuses in series to simulate the usual two fuses that are in a circuit. Two 600-volt fuses were also tested in this circuit, wherein the available currents were varied from 10,000 to 96,000 amperes in several steps, and the results were perfect. The build-up of the current in this circuit was much slower than in an a-c circuit so that the current-limiting effects were much more pronounced as shown in Figure 7.

In the three-phase 440-volt a-c circuit one 250-volt fuse of the above type was connected in each supply line, and the available currents ranged from 18,000 to 84,000 symmetrical rms amperes. The resulting currents are shown in Figure 6, and the performance was perfect. When the supply power was 600 volts, then one 600-volt fuse was connected in each supply line, and the available current ranged from 24,000 to 114,000 amperes. The results, which were perfect in operation, are also shown in Figure 6. It can therefore be said that with this arrangement of connections, these fuses are capable of interrupting a circuit, either a-c or d-c, which has an available short-circuit current of 100,000 amperes.

Conclusions

The following recommendations are made:

1. Correctly designed overload relays should be used to protect all sizes of motors against overloads. To do this, relays having three degrees of tripping speeds should be available—fast, medium, and slow tripping.

2. Every motor should be listed in one of three groups to show whether it is a fast-, medium-, or slow-heating unit. The correct overload relay could then be selected for each motor.

3. Full short-circuit protection for NEMA size 3 and smaller starters can be obtained by the use of correct-size nonrenewable cartridge-type fuses of a good design. Interrupting devices which are slower than these fuses may not give full protection.

4. NEMA size 4 and larger starters will be protected by fast-tripping air circuit breakers which have an instantaneous type of tripping device.

5. The copper cross section of the branch circuit, the control, and the motor should be equal to or larger than the reduced cross section of the zinc fuse link, and the cross section of the Nichrome of the overload relays should be 2.2 times larger than the zinc fuse link.

6. Since safety first laws are becoming more stringent, since available short-circuit energy is rapidly increasing, and since starters are frequently mounted near workmen, it is quite essential that adequate short-circuit protection be provided for all branch-line circuits. Since it has been demonstrated that this protection can be provided for standard existing starters by means of standard fuses, even on large power systems, it was considered of sufficient importance to bring it to your attention at this time so that this needed protection can be obtained and especially during this critical war period.

Reference

1. AIEE Standards Pamphlet No. 1 A, September 1941. (Proposed supplement to AIEE Standards Pamphlet No. 1.)

Selenium Rectifiers and Their Design

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Synopsis: Selenium rectifiers are dry-plate rectifiers of the electronic type. The history of dry rectifiers began some 30 years ago with the advent of the copper-sulphide rectifier. In the early 20's, the copper-oxide type came into common use, and during the past three years, selenium rectifiers have found wide application in American industry. Fundamentally, this third and latest type of rectifier is a continental development and has been manufactured in Europe within the International Telephone and Telegraph group of companies during most of the 1930's. Sufficient experience was gained in the technique of manufacture, as well as in methods of design and in selection of applications, to warrant engineering statements as to their general usefulness and importance to industry.

The purpose of this paper is to outline general principles of design of stacks, one or more of which make a rectifying unit. Starting with the availability of selenium plates or discs of various types, the engineer is confronted with the problem of

1. Selecting the proper size of plate to provide the required d-c output.

2. Computing the required a-c voltage to be impressed on the rectifier stacks to give the necessary d-c output.

3. Analyzing various factors such as type of load, nature of service, and cost of selected rectifier.

The paper includes dynamic and other characteristics of the principal sizes of selenium rectifier plates as applied to the design of single-phase, three-phase, full-wave, and half-wave rectifier units, and all variety of loading. Typical circuits are analyzed and novel representative computations of rectifier units are included.

Selenium Plates

THE rectification of alternating currents by means of the selenium rectifier takes place wholly within the constituent plate or plates, seven sizes of which are shown in Figure 1. The rectifying medium of this electronic device consists of selenium; the principle of operation is similar to that of other dry plate rectifiers, that is, low resistance in the forward direction, and high resistance in the reverse direction. A metal plate serves as back electrode; over it a layer of selenium is deposited, thin enough to give minimum internal losses, but sufficiently thick to withstand high inverse voltage. A soft metal of low-melting temperature is then applied over the selenium layer to form a front electrode. Finally, by means of controlled processes, a barrier layer is formed between the selenium and the front electrode.

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Selenium Rectifier Stacks

Rectifier stacks are produced by assembling selenium rectifier plates (40 plates are usually maximum) on a center stud with contact discs or washers interspersed between plates. Series and parallel arrangement can readily be provided as required, by inserting insulators between plates and introducing terminal lugs into the stack.

A stack consisting of 40 plates may be connected in several different ways: for example, as a bridge-circuit unit having ten plates in a series and one plate in parallel (4-10-1), or one plate in series and ten in parallel (4-1-10). The same stack may also be connected as a half-wave rectifier having all 40 plates in series to take care of voltage and one plate in parallel to take care of current (1-40-1). Further, the 40-plate stack may also be assembled as a doubler (2-10-2), two of which make a bridge-circuit rectifier with ten series and two parallel plates in each arm of the bridge.

For the three-phase half-wave circuit the total number of plates must be a multiple of three to allow a total connection such as 3-6-2 for a 36-plate single-stack unit. Similarly, this latter stack, if connected as 6-6-1, becomes either a bridge or center-tap three-phase rectifier.

Rating of Plates

Current ratings of selenium plates are a function of their effective rectifying areas and heat-dissipating capacities. Table I lists seven basic plates, ranging from $^3/_4$ to $4^3/_8$ inches in diameter; it also shows ratings of the basic plates in various rectifier circuits. The ampere capacities shown in this table are based on an ambient temperature of 35 degrees centigrade and were determined experimentally. The requirements of a selenium rectifier in respect to current are always met by selecting the proper size of plates and their number in parallel, if the total rating of the rectifier exceeds the rating of an individual plate.

The ratings of the plates shown in Table I can be increased by providing additional cooling. Doubling the spacing between plates assembled in a single stack increases the heat-dissipating ability of the stack; the rating of plates is some 25 to 50 per cent higher than those shown in Table I. Table II lists six selenium plates having the same effective rectifying areas as those listed in Table I, but their current ratings are higher because of wider spacing.

By providing cooling fins, the forward current-carrying capacity of the plates can be raised still further. Table III contains eight additional plates with fins, the current ratings of which are from 2 to $2^1/_2$ times greater than the plates of the same rectifying areas listed in Table I. With extended ratings of the plates, whether by means of wide spacings or cooling fins, the internal losses of selenium rectifiers are greater; consequently, their efficiency is slightly reduced, and the voltage regulation is adversely affected.

Figure 1 (Below left). Cross section of a selenium rectifier plate showing the sequence of various layers
(Right) Seven basic sizes of selenium rectifier plates

Tables I, II, and III also give the maximum permissible reverse rms voltages per plate. The voltages thus indicated have ample safety margin. If, however, the reverse voltage be increased beyond safe limits, the rectifying layer between the selenium and the front electrode alloy breaks down. The maximum specified voltage must not, therefore, be exceeded. Tables I, II, and III include ratings of selenium plates in d-c circuits.

Rectifier stacks with narrow or wide spacing, as well as those with fins, are ordinarily cooled by convection. Large-size selenium rectifiers, however, often utilize forced draft ventilation in order to save space and to economize in rectifying elements. The normal plate rating can thereby be increased twofold and sometimes threefold. If, however, extended loading of plates with the aid of forced ventilation is not desired, substantially greater current output, as compared with free air conditions, can be obtained by mounting the stacks in a chimneylike enclosure (Figure 2). As will be noted from the figure, the least favorable condition is that of mounting the stacks in a cabinet provided with perforated covers.

The current rating of selenium rectifiers is limited only by the final plate temperature resulting from heating. The stacks can be heavily overloaded, provided the maximum safe operating temperature of 75 degrees centigrade is not exceeded. When this temperature is reached, either the load must be reduced to normal, or provision must be made for cutting the rectifying elements out of service as in the two half-wave rectifiers illustrated in Figure 3, widely used in business machines. Each element in these machines is equipped with a pair of bimetal strips connected by means of an adjustable screw. If, by chance, the key punch or the duplicator happens to be jammed and causes the temperature of the stacks to reach a range of 70 or 80 degrees centigrade, the bimetal

Table I. Current and Voltage Ratings of Seven Basic Selenium Plates When Used in Narrow Spacing Assemblies and With Resistive and Inductive Loads

For Battery-Charging and Capacitive Loads, These Ratings Are Reduced by 20 Per Cent. Conditions: Continuous Duty; 35 Degrees Centigrade Ambient Temperature

Plate Type No.	Diameter of Plates (Inches)	Maximum Number of Plates Per Stack	Maximum RMS Reverse Voltage Per Plate (Volts)	Single-Phase Rectifiers			Three-Phase Rectifiers			35 C Ambient Rating of Plates Used as D-C Valves	
				Half-Wave	Bridge	Center-Tap	Half-Wave	Bridge	Center-Tap		
				D-C Amperes						Amperes	Volts
1	3/4	36	18	0.04	0.075	0.075	0.10	0.11	0.13	0.06	15
2	1	36	18	0.075	0.15	0.15	0.20	0.225	0.27	0.12	15
3	1 1/4	36	18	0.15	0.30	0.30	0.40	0.45	0.55	0.23	15
4	1 3/4	40	18	0.30	0.60	0.60	0.80	0.90	1.1	0.45	15
5	2 3/4	40	18	0.60	1.2	1.2	1.6	1.8	2.2	0.90	15
6	3 3/4	40	16	1.2	2.4	2.4	3.2	3.6	4.5	1.8	12
7	4 3/4	40	14	2.0	4.0	4.0	5.3	6.0	7.5	3.1	12

Table II. Current and Voltage Ratings of Six Selenium Plates (Similar to Table I, Except Number 1 Plate Omitted) When Used in Wide Spacing Assemblies and for Resistive and Inductive Loads

For Battery-Charging and Capacitive Loads, These Ratings Are Reduced by 20 Per Cent. Conditions: Continuous Duty; 35 Degrees Centigrade Ambient Temperature

Plate Type No.	Diameter of Plates (Inches)	Maximum Number of Plates Per Stack	Selenium Plate No. Used (See Table I)	Maximum RMS Reverse Voltage Per Plate (Volts)	Single-Phase Rectifiers			Three-Phase Rectifiers			35 C Ambient Rating of Plates Used as D-C Valves	
					Half-Wave	Bridge	Center-Tap	Half-Wave	Bridge	Center-Tap		
					D-C Amperes						Amperes	Volts
20	1	28	2	18	0.11	0.22	0.22	0.29	0.33	0.4	0.17	15
21	1 1/4	28	3	18	0.23	0.45	0.45	0.6	0.67	0.82	0.34	15
10	1 1/4	28	4	18	0.39	0.78	0.78	1.0	1.1	1.4	0.58	15
11	2 3/4	28	5	18	0.78	1.6	1.6	2.1	2.3	2.8	1.2	15
14	3 3/4	28	6	16	1.5	3.1	3.1	4.1	4.6	5.8	2.4	12
18	4 3/4	28	7	14	2.6	5.2	5.2	6.9	7.8	9.7	4.0	12

Table III. Current and Voltage Ratings of Eight Selenium Plates (Numbers 4, 5, 6, and 7) Equipped With Cooling Fins of Different Sizes, and Used for Resistive and Inductive Loads

For Battery-Charging and Capacitive Loads, These Ratings Are Reduced by 20 Per Cent. Conditions: Continuous Duty; 35 Degrees Centigrade Ambient Temperature

Plate Type No.	Size of Cooling Fins (Inches)	Maximum Number of Plates Per Stack	Selenium Plate No. Used (See Table I)	Maximum RMS Reverse Voltage Per Plate (Volts)	Single-Phase Rectifiers			Three-Phase Rectifiers			35 C Ambient Rating of Plates Used as D-C Valves	
					Half-Wave	Bridge	Center-Tap	Half-Wave	Bridge	Center-Tap		
					D-C Amperes						Amperes	Volts
9	2 3/4 Diameter	28	4	18	0.58	1.1	1.1	1.5	1.7	2.1	0.87	15
12	3 1/4 Diameter	28	5	18	0.90	1.8	1.8	2.4	2.7	3.3	1.4	15
13	4 3/4 Diameter	28	5	18	1.1	2.2	2.2	2.9	3.3	4.0	1.7	15
15	4 1/4 Diameter	28	6	16	1.8	3.5	3.5	4.6	5.2	6.5	2.7	12
16	4 1/4 Diameter	24	6	16	1.9	3.8	3.8	5.0	5.6	7.0	2.9	12
17	6 x 6	28	6	16	2.7	5.4	5.4	7.2	8.1	10.0	4.1	12
19	6 x 6	28	7	14	3.7	7.4	7.4	9.8	11.1	13.3	5.7	12
8	8 x 8	28	7	14	5.0	10.0	10.0	13.0	15.0	18.0	7.5	12

strips separate, thus breaking the circuit. The plates then cool off and the bimetal strips again close (Figure 4).

Intermittent Service

Considerable gain in the current capacity of selenium rectifiers can be obtained when they are used in intermittent service, in which case, the duty cycles must be definitely established. The variety of these intermittent applications is great, and their complete discussion here would be too lengthy. One formula, however, is frequently used for periodic loadings:

$$I_m = I_{max}\sqrt{\frac{A}{A+P}} \qquad (1)$$

where I_m is the continuous current rating, I_{max} the maximum current drawn periodically, A the operating period, and P the inoperative interval; both A and P should be in the same units. Experience has shown that this formula can be used only if A is less than the selenium plate time constant T, which may be defined by:

$$t_1 = t_2\left(1-e^{-\frac{A}{T}}\right) \qquad (2)$$

and which varies from five to eight minutes, depending on the plate size (t_1 and t_2 are instantaneous and final plate temperatures, respectively). When operating periods are separated by inoperative intervals of such length that the rectifier again cools practically to normal ambient temperature, much greater plate overloads are practicable.

Design of Stacks by Direct Values

After choosing the size of plate with proper current-carrying capacity, the internal voltage drop of the plate is considered. Figure 5 illustrates the average experimentally determined internal voltage drop for seven plates in either bridge or center-tap single-phase circuits. The

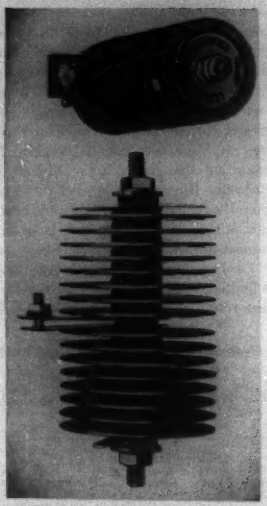


Figure 3. Two half-wave selenium rectifiers for operation of magnets in business machines

Both stacks are equipped with bimetal strips to open the circuit when the plate temperature exceeds a specified value

voltage drop per plate, designated as dv, is one half of the difference between the rms values of voltages read on the input and output side of the rectifier. These quantities are plotted as ordinates against the arithmetical values of output current in amperes plotted as abscissa.

The output voltage of a selenium rectifier is determined by the input voltage V_{ac} less the total voltage drop within the rectifier. The computation of the necessary a-c voltage to be impressed on the selenium rectifier involves consideration of the voltage drop per plate and the number of plates through which the current flows.

Using the data given in Tables I, II, and III, and the internal voltage drop per plate illustrated in Figure 5, any single-phase selenium rectifier can be designed and the necessary a-c voltage computed by the following formula:

$$V_{ac} = k_1 V_{dc} + k_2 n \text{ dv} \qquad (3)$$

where V_{ac} is the input voltage, k_1 the form factor to convert the rms voltage value (Table IV), V_{dc} the required d-c output voltage, k_2 the number of arms through which the current must pass in the circuit for each half-cycle, n the number of plates in series per arm, and dv the voltage drop per plate for the circuit employed. The constants k_1 and k_2 vary depending upon whether a bridge or center-tap connection, a single or three-phase circuit is employed.

As an example, let us design a bridge-type unit required to deliver four amperes at 16 volts continuously under the maximum ambient temperature of 35 degrees centigrade in a single-phase circuit. Selenium plate 7, $4^3/_8$ inches in diameter

Table IV. Selenium-Rectifier Design Constants: k_1 = Form Factor; n = Number of Plates in Series; k_2 = Circuit Factor; V_p = Maximum Voltage Per Plate; V_{ac} = Phase Voltage, Except Three-Phase Bridge Where It Is Line Voltage

Number of Phases	Circuit Type	k_1	n	k_2
1	Half-wave	2.3	$\frac{V_{ac}}{V_p}$	1
1	Bridge	1.15	$\frac{V_{ac}}{V_p}$	2
1	Center-tap	1.15	$\frac{2V_{ac}}{V_p}$	1
3	Half-wave	0.855	$\frac{\sqrt{3}V_{ac}}{V_p}$	1
3	Bridge	0.74	$\frac{V_{ac}}{V_p}$	2
3	Center-tap	0.74	$\frac{2V_{ac}}{V_p}$	1

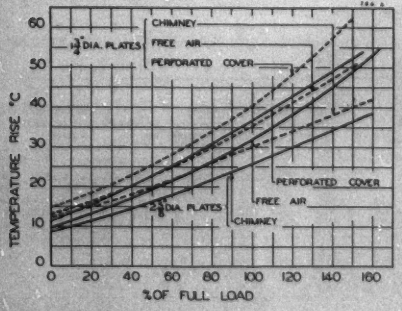


Figure 2. Temperature characteristics of two selenium rectifiers under three different cooling conditions

1. In a cabinet with perforated top and bottom covers
2. In free air
3. In a chimney-like enclosure fully open at the top and bottom

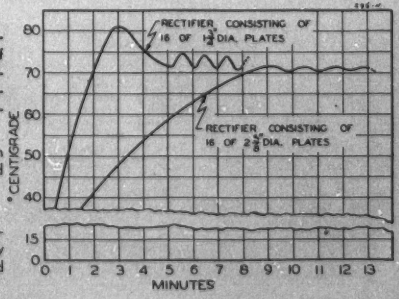


Figure 4. Time-temperature characteristics illustrating the performance of selenium rectifiers equipped with bimetal strips (Figure 3)

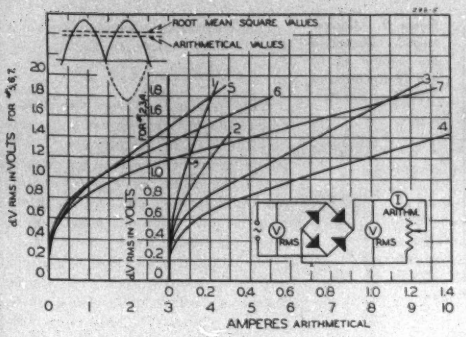


Figure 5. Rectification characteristics of seven basic plates ($^3/_4$, 1, $1^3/_8$, $1^3/_4$, $2^3/_8$, $3^3/_8$, and $4^3/_8$ inches in diameter) used in the design of single-phase bridge and center-tap rectifiers for inductive and resistive loads

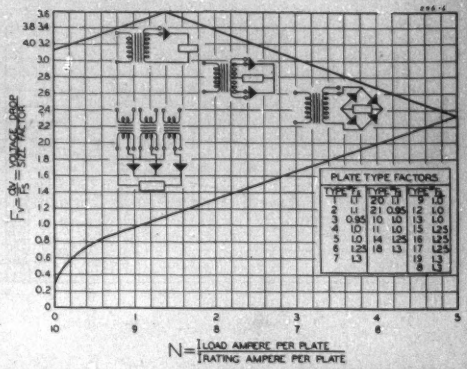


Figure 6. Characteristic illustrating the relation of F_v and N for single-phase half-wave, center-tap, and bridge rectifier circuits with resistive or inductive load; also for three-phase half-wave rectifier circuit with all types of load

(listed in Table I and rated at four amperes) will serve the purpose. Using equation 3 and corresponding constants from Table IV:

$$V_{ac} = 1.15 \times 16 + 2n\,\mathrm{dv}$$

The number of plates in series, that is, quantity n, necessary at this stage, can be computed by the following formula:

$$n = \frac{k_1 V_{dc}}{V_p - 2\,\mathrm{dv}} \qquad (4)$$

V_p for plate 7 is 14, and dv, as read off characteristic 7 in Figure 5, is 1.29; hence

$$n = \frac{1.15 \times 16}{14 - 2 \times 1.29} = 1.6 \text{ or 2 of number 7 plates in series}$$

Figure 7. Characteristic illustrating the relation of F_v and N for single-phase half-wave, center-tap, and bridge rectifier circuits for battery-charging application or capacitive loads

V_{ac}, therefore, at the start of service, is equal to 23.6 volts. With the aging of the selenium rectifier, the forward resistance increases, and the inverse resistance also slightly increases. Based on lengthy experience in the design and application of these rectifiers, it can be stated that the only variable quantity of equation 3 is dv, which may increase as much as 50 per cent under most adverse conditions. An additional tap, therefore, should be provided in the transformer winding to give the V_{ac} required for the aged condition:

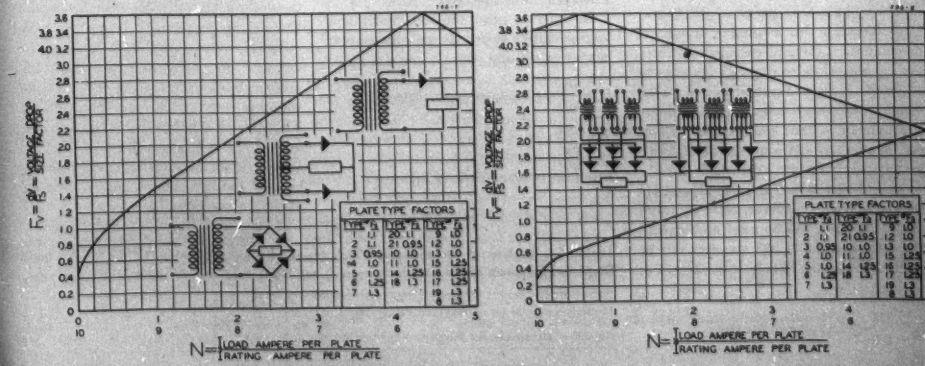
$$V_{ac} = 1.15 \times 16 + 2 \times 2 \times 1.29 \times 1.5 = 26 \text{ volts}$$

Designs by Relative Values

The foregoing example and reference to Figure 5 characteristic apply only to the single-phase bridge and center-tap designs with either inductive or resistive loads. With capacitive and battery-charging loads, even in the above-mentioned circuits, intermittent loading on the selenium plates occurs with periodic values of the forward current greater than the periodic values for the same d-c output feeding resistive or inductive load; voltage drops per plate are, therefore, greater in the former case. Applications occur, however, where the voltage drop per plate is smaller than the values shown in Figure 5. An example is the three-phase circuit where the rectified current is practically at the peak value of the applied alternating current. The output current density per plate in these circuits is considerably higher than in the case of a single-phase bridge circuit; furthermore, the type of load, whether it be resistive, inductive, capacitive, or battery charging, has practically no effect on the voltage drop per plate.

Inasmuch as a wide variety of circuits and types of loading is encountered, a

Figure 8. Characteristic illustrating the relation of F_v and N for three-phase center-tap and bridge rectifier circuits for all types of loads



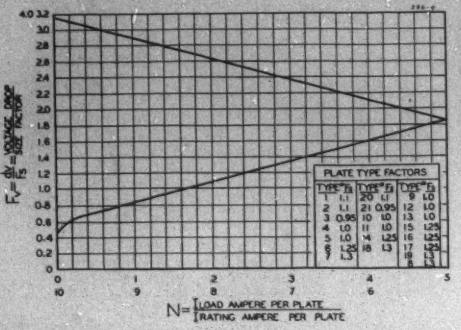


Figure 9. Characteristic illustrating the relation of F_s and N for d-c and blocking circuits

method for rating the 21 rectifier types according to relative values of output current and voltage drop per plate has been developed. Figures 6, 7, 8, and 9 illustrate the relationships N and F_s for various types of circuits and loads.

The use of these characteristics involves first, determination of the value N, which is obtained by dividing the actual ampere load per plate by the ampere rating of the basic plate employed. With this value determined, the value of F_s is read from one of the characteristics and then multiplied by the plate size factor F_s to obtain the actual voltage drop per plate, dv for the plate selected.

Figure 6 illustrates the relationship of F_s to the value N for half-wave, center-tap, and bridge single-phase circuits when loaded with either resistive or inductive load; also for half-wave three-phase circuits for all types of loads. Figure 7 gives a similar relationship for F_s to the value N for half-wave, center-tap, and bridge circuits, all single-phase for capacitive or battery-charging applications. Figure 8 shows the relationship of F_s to N for three-phase bridge and center-tap circuits for all types of loads. Finally, Figure 9 shows the relationship of F_s to N for d-c and blocking circuit applications.

To illustrate this method of design, let us compute a three-phase selenium rectifier capable of delivering 325 amperes at 13 volts for the filament supply of a television transmitter tube. An additional requirement is that the rectifier deliver not more than 488 amperes at approximately two volts into tube when cold.

Several plates in Tables I, II, and III should be tried; however, plate 13, rated at 3.3 amperes, will be most economical; the total current of 325 amperes can be safely handled by 100 plates connected in parallel.

$$I_{dc}=\frac{325}{100}=3.25 \text{ amperes per plate}$$

This plate loading with 1.8 ampere rating for basic plate 5 used in type 13 will give

$$N=\frac{3.25}{1.8}=1.8$$

From Figure 8, $F_s=1.07$ and $dv=1.07\times 1=1.07$.

In aging, the dv value may increase 50 per cent, and thus becomes 1.6. Substituting the known quantity in formula 4:

$$n=\frac{0.74\times 13}{18-2\times 1.6}=0.65;\ \text{or 1 plate in series}$$

The foregoing proves that the entire rectifier should consist of a total connection of (6-1-100), where the first number (6) designates the number of arms of the three-phase circuit, the second number (1) indicates the number of plates in series, and the third number (100) gives the number of plates in parallel. The total of 600 plates of type 13 may be conveniently assembled into 24 stacks, each having 25 plates in parallel.

Using formula 3 and the design constants of Table IV:

$V_{ac}=0.74\times 13+2\times 1\times 1.07=11.8$ volts

when rectifying elements are new;

$V_{ac}=0.74\times 13+2\times 1\times 1.6=12.8$ volts

when they are fully aged.

In order to meet the requirements of approximately two volts with the current output of 488 amperes:

$$I_{dc}=\frac{488}{100}=4.88 \text{ amperes per plate}$$

$$N=\frac{4.88}{1.8}=2.7$$

From the characteristic of Figure 8

$F_s=1.37$

For the new stacks, therefore, $dv=1.37\times 1=1.37$, and for fully aged stacks

$dv=1.37\times 1.5=2.06$

Using formula 3 and these two values of dv, the new and aged V_{ac} will be found to be 4.2 and 5.6 volts, respectively. The 50 per cent limit for the current requirement is actually met by the external limiting reactances in each phase of the three-phase circuit. The complete assembly of this rectifier is shown in Figure 10.

The ordinary single-phase bridge-type rectifier for resistive loading can also be designed through the use of relative values. Figure 11 illustrates a two-ampere, 120-volt telautograph unit.

With two number 9 plates in parallel, or one ampere per plate:

$$N=\frac{1}{0.6}=1.67$$

From the characteristic of Figure 6

$F_s=1.2$ $\qquad$ $dv=1.2\times 1.0=1.2$

Hence

$$n=\frac{1.15\times 120}{18-2\times 1.2\times 1.5}=9.6,\ \text{or 10 plates in series}$$

The total connection of the rectifier is then 4-10-2. Practical considerations suggest four stacks, two of which make one bridge with ten plates in each arm of the bridge. Again, from formula 3, corresponding constants of Table IV and the above dv value, V_{ac} is found to be 162 volts when new and 174 volts when aged.

Ratings (Tables I, II, and III) of selenium rectifier plates, functioning as blocking valves in d-c circuits, are higher in current and lower in voltage value than they are in half-wave alternating circuits. The higher current rating is acceptable, inasmuch as the forward resistance ordinarily decreases when only forward current passes through the selenium rectifier plates. The reverse current of the blocking unit, on the other hand, is higher, and the safe voltage limit is, therefore, more conservatively established than for a-c circuits. As an example, a 30-volt, 4.5-ampere blocking unit consists of a total connection of 1-2-5 number 5 plates. The value N for this unit is equal to one, and dv is 0.84 (Figure 9).

Experience has shown that for constant-current battery-charging and capacitive loading, the current rating should be only

Table V. Relation of Factor k_3 by Which Normal Rating of Number 7 (That Is, 4³/₈-Inch-Diameter) Selenium Plates Can Be Increased, and the Speed and Amount of Air Necessary

Multiplying factor for normal plate ratings, k_3	1	1.5	2	2.5	3	3.5	4	4.5
Air speed in feet per minute	0	60	90	120	160	200	310	400
Cubic feet per minute per plate	0	0.5	0.8	1.1	1.4	1.7	2.8	3.7

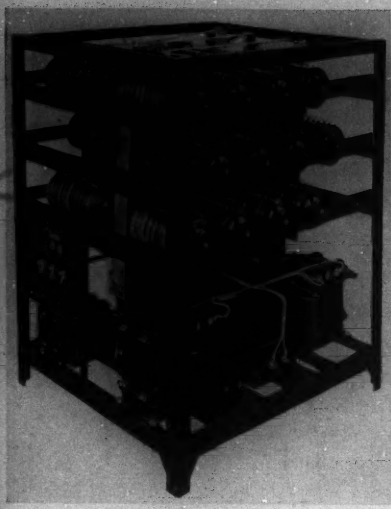


Figure 10 (left). Rectifier unit of 325-ampere 13-volt rating with reactances limiting output current to 488 amperes at two volts

A-c input: 220 volts, three phases, 60 cycles. Rectifying element consists of 600 plates arranged in 24 stacks, each stack consisting of 25 plates in parallel

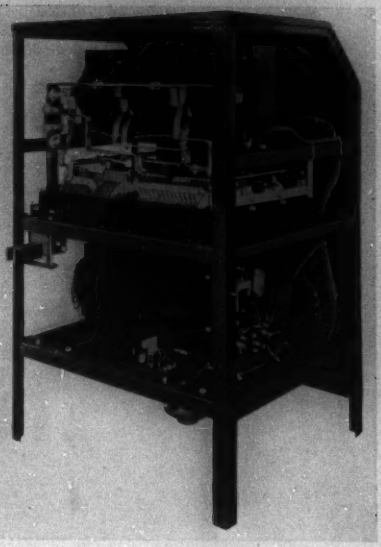


Figure 12 (right). Three-phase selenium rectifier unit employing forced-draft ventilation for output of 600 amperes at six volts

Over-all efficiency: 74 per cent; power factor: 94 per cent

80 per cent of the values tabulated in Tables I, II, and III. In the design of the rectifier for charging a 60-cell battery at the rate of 0.4 ampere, with 2.4 volts per cell, plate 4 may be selected. The value of N is 0.67. The new dv, as read off the characteristic of Figure 7, is 1.25 and, after aging, it becomes 1.87. The number of plates in series is determined either by

$$n = \frac{V_b}{V_p} \tag{5}$$

$$\text{or } n = \frac{V_b/\sqrt{2}}{V_p - 2\,\text{dv}} \tag{6}$$

depending on which is greater.

Figure 11. Selenium rectifier with output of two amperes at 120 volts for powering teleautograph equipment

$$V_{ac} = \frac{V_b}{\sqrt{2}} + k_3 n \text{ dv} \tag{7}$$

$$= \frac{60 \times 2.4}{\sqrt{2}} + 2 \times 8 \times 1.25 = 122 \text{ volts}$$

An additional tap to give 132 volts for the fully aged condition of the stacks should be provided.

Design of Forced-Draft-Ventilation Unit

The extended current rating of selenium rectifier plates with forced draft or fan cooling and the speed of air constituting the forced ventilation require further consideration. A rather conservative relationship of current rating to air velocity has been established and successfully used for the $4^3/_8$-inch-diameter number 7 plate (Table V).

As an example, let us design a three-phase full-wave rectifier supplying a d-c output of 600 amperes at six volts. Because of the low required output voltage, as compared to the full rms voltage permissible for the number 7 plate, the center-tap circuit is most economical and gives greatest efficiency. With the fan delivering air at a speed of 120 feet per minute, the 7.5-ampere (Table I) loading of this plate can be increased 2.5 times (Table V), thus making it 18.7 amperes per plate. Practical consideration of possible 10 per cent overload suggests that this unit should have 36 plates in parallel for the total current output of the unit. This makes the value N (Figure 8) equal to 2.22, and the initial and aged dv equal to 1.6 and 2.4 respectively. The total connection of the rectifier is, therefore, 6-1-36. The new V_{ac} for half of the transformer secondary voltage is 6.1 volts, and for the fully aged condition 6.9 volts. A view of this equipment is shown in Figure 12.

Voltage Regulation

The inherent voltage regulation of the selenium rectifier is in the neighborhood of 10 to 20 per cent. In computing the regulation, one must determine the no-load

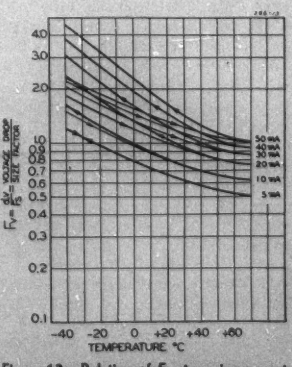


Figure 13. Relation of F_s at varying current densities to the ambient temperatures throughout a heating and cooling cycle

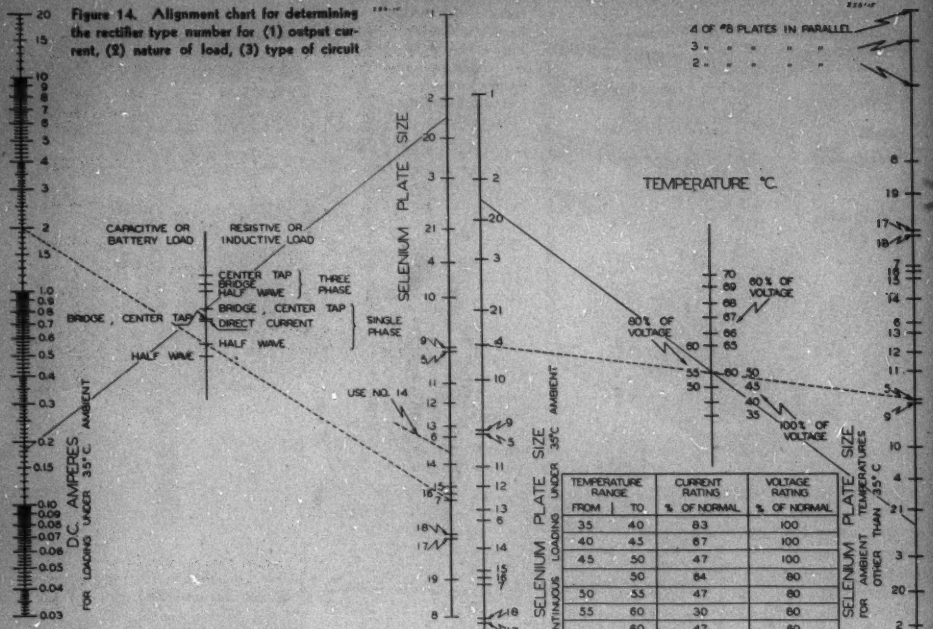

DC. AMPERES FOR LOADING UNDER 35° C AMBIENT
CAPACITIVE OR BATTERY LOAD
RESISTIVE OR INDUCTIVE LOAD
CENTER TAP BRIDGE HALF WAVE
THREE PHASE
BRIDGE, CENTER TAP DIRECT CURRENT
HALF WAVE
SINGLE PHASE
BRIDGE, CENTER TAP
HALF WAVE
SELENIUM PLATE SIZE
USE NO. 14
SELENIUM PLATE SIZE FOR CONTINUOUS LOADING UNDER 35°C AMBIENT
4 OF 48 PLATES IN PARALLEL
3 " " " "
2 " " " "
TEMPERATURE °C
60% OF VOLTAGE
60% OF VOLTAGE
100% OF VOLTAGE
SELENIUM PLATE SIZE FOR AMBIENT TEMPERATURES OTHER THAN 35° C

Figure 14. Alignment chart for determining the rectifier type number for (1) output current, (2) nature of load, (3) type of circuit

TEMPERATURE RANGE		CURRENT RATING	VOLTAGE RATING
FROM	TO	% OF NORMAL	% OF NORMAL
35	40	83	100
40	45	67	100
45	50	47	100
	50	84	80
50	55	47	80
55	60	30	60
	60	47	60

Figure 15. Alignment chart for determining the selenium-rectifier plate number required in ambient temperatures above 35 degrees centigrade. Also, table of percentage of current and voltage ratings at ambient temperatures above 35 degrees centigrade

value of dv and then the no-load output voltage. In the case of the first example of a four-ampere, 16-volt rectifier, the dv value from Figure 5 is 0.4. The d-c output voltage, therefore, at no load is

$$V_{dc} = \frac{23.6 - 2 \times 2 \times 0.4}{1.15} = 19.1$$

$$\text{Regulation} = \frac{19.1 - 16}{16} \times 100 = 19.4 \text{ per cent}$$

Similarly, the regulation of the three-phase 325-ampere 13-volt unit (Figure 10) is computed by reading F_s for N equal to zero in Figure 8. Substituting 0.3 for the value of dv in formula 3, and taking 11.8 volts for V_{ac}, one finds the no-load voltage to be 15 volts, and the voltage regulation is, therefore, 15.4 per cent.

Efficiency

The efficiency of selenium rectifiers varies with the type of circuit and the nature of the load. The single-phase circuits with fully loaded plates in respect to voltage and current, and when feeding either resistive or inductive loads, give an efficiency of approximately 64 per cent; the same circuits, when used for battery charging give an efficiency some 14 per cent higher due to the greater value of the rectified voltage. The three-phase circuits give efficiency values in the neighborhood of 83 per cent and, for all practical purposes, remain the same irrespective of the type of load. For all circuits and loads, however, the efficiency of selenium rectifiers increases with decrease of load down to approximately 25 per cent of full value, and thereafter falls off rapidly.

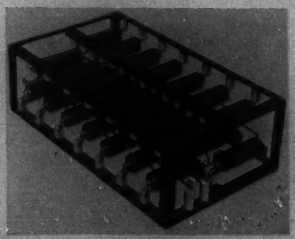


Figure 16. Single-phase bridge-connected rectifier

Output: 180 milliamperes at 2,300 volts under ambient temperatures from −40 to +60 degrees centigrade

The efficiency itself depends on the combined losses in the selenium rectifier from forward and reverse currents, and, in formula form, it is:

$$\frac{V_{dc} I_{dc}}{(V_{dc} I_{dc}) + W_f + W_r} \times 100 = \% \text{ efficiency} \quad (8)$$

where W_f are losses due to forward current, and W_r are losses due to the reverse current.

The computation of exact efficiency of all sizes of plates and various loads and circuits is rather involved and constitutes an extensive subject in itself.

In order to illustrate the simplified method of efficiency computation and the effect of dv changes on its value, let us compute the efficiency of the 325-ampere 13-volt three-phase unit illustrated in Figure 10.

Forward losses per plate in the three-phase bridge circuit are

$$w_f = \frac{\sqrt{2} I_{dc}\, dv}{3}$$

where $\sqrt{2}$ is a conversion factor for approximating the peak value of the a-c

wave in terms of effective value of dv. Divisor 3 results from the fact that in three-phase bridge circuit each plate is utilized $2\times{}^1/_6$ times in each cycle.

$$w_f=\frac{325/100\times\sqrt{2}\times1.07}{3}=1.64 \text{ watts per plate}$$

or $W_f=6\times100\times1.64=984$ watts for all 100 plates in six arms.

The reverse losses are approximately one third of forward losses computed for the normal rating of the plate used in this unit

$$W_r=\frac{1}{3}\times\frac{6\times100\times0.8\times\sqrt{2}\times1.8}{3}=136 \text{ watts}$$

The new input wattage W, therefore, is

$$W=(I_{dc}\times V_{dc})+W_f+W_r$$
$$=(325\times13)+984+136=5{,}345 \text{ watts}$$

$$\text{Efficiency}=\frac{4{,}225}{5{,}345}\times100=79.2 \text{ per cent}$$

Similarly, assuming a possible 50 per cent change in dv, the efficiency of this rectifier with stacks fully aged is computed as 72 per cent.

The foregoing designs illustrate the importance of the quantity dv, which is dependent on the forward resistance and current density of the plates, as well as the ambient temperature under operating conditions. Its changing values under varying conditions greatly influence the efficiency, regulation, and aging of selenium rectifiers. The ambient temperature and current density relationships affecting the value of dv are illustrated in Figure 13. The arrows on the curves indicate that the resistance of the plates decreases with increase of temperature. As the plates cool off, the resistance again increases, and dv is greater at the new lower temperatures than during the rising-temperature phase of the heating cycle. This phenomenon diminishes with lower current densities to a point where the resistance is the same at corresponding temperatures of the heating and cooling portions of the cycle.

Selection of Plate Type for 35 Degrees Centigrade and Higher Ambient Temperature

Almost invariably more than one selenium plate type appears suitable for given output requirements. The type of circuit or nature of loading, as well as the cost, however, restricts the choice.

The alignment chart (Figure 14) has been found useful in selecting plate types for specified output currents. If a straight edge is laid connecting the required d-c output with the type of circuit and the nature of load, the intersection of the straight edge on the plate size scale gives the type number of the required rectifier plate. If the intersection falls between two plate type numbers, the plate having the higher current rating should be chosen.

For ambient temperatures higher than 35 degrees centigrade, the plate type number for a 35 degrees centigrade ambient should first be found. Referring to Figure 15, a straight edge connecting the 35 degrees centigrade ambient temperature plate type number with the desired higher ambient value of the temperature scale intersects the right-hand scale, indicating the required higher ambient plate type number. Again, if the intersection is between two plate type numbers, the plate type number with the higher current rating should be used. It will be noted that, by decreasing the voltage rating, a small increase in current rating is allowable.

As an example, let us design a high-voltage low-current rectifier of the type illustrated in Figure 16 for either resistive or inductive load. Referring to Figure 14, the line drawn through the 0.18 reading on the left-hand scale, and the point marked "single-phase bridge" in the middle of the chart, intersects the right-hand scale between "2" and "20." Thus, plate 20 (Table II) would be used if the rectifier is to operate under maximum ambient temperature of 35 degrees centigrade. In order to derate plate 20 for a 60 degrees centigrade ambient, reference is made of Figure 15. The line drawn on this chart through the same point (between "2" and "20") of the left-hand scale (as in Figure 14) and the point marked "60 per cent of voltage" indicates that the number 21 selenium plate (Table II) should be used for the required assembly. Further computations of quantities N, dv, and n result in the design of a rectifier with total connections of 4-224-1, arranged in 28 stacks, each consisting of 32 of $1^1/_8$-inch plates in series.

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Rectifier Terminology and Circuit Analysis

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ANYONE reading several articles on the subject of rectifiers must be impressed by the confusion caused by a lack of exact terminology. This paper presents definitions of a few terms representing the most important concepts arising in the rectifier field. The definitions are presented with the hope that they will be found sufficiently useful to be widely adopted. Constructive criticism of the terms and definitions is invited.

These terms have been defined to conform with the general practice in the power-rectifier field. It is to be hoped, however, that the concepts will be sufficiently broad and accurate to be generally useful in all fields where rectifiers are employed.

In many of the definitions the term "circuit element" is employed. This has not been defined, because it is in general use in electrical literature and has been defined elsewhere.[1] The definitions suggested are given below.

Rectifier Terms

1. Rectifying Element. A rectifying element is that circuit element which has the property of conducting current effectively in only one direction.

In arc rectifying devices, the portion of the circuit including an anode, its cathode, and the arc space between the anode and cathode, is the rectifying element.

When a group of rectifying units is connected, in either parallel or series arrangement, to operate as one circuit element, the group of rectifying units should be considered as a rectifying element.

2. Double-Way Rectifier (Double-Direction Rectifier). A double-way rectifier is a rectifier in which all parts of the alternating-voltage circuit elements, conductively connected to the rectifying elements, conduct current in both directions (that is, in alternate half-cycles).

3. Single-Way Rectifier (Single-Direction Rectifier). A single-way rectifier is one in which no portion of the alternating-voltage circuit elements, conductively connected to the rectifying elements, conducts current in both directions (that is, in alternate half-cycles) because of the action of the rectifying elements.

4. Simple Rectifier. A simple rectifier is a rectifier in which the total direct current at any instant, exclusive of the commutating time, flows through a single rectifying element for a single-way rectifier, or flows through two rectifying elements in series (one on either side of the a-c circuit element) for a double-way rectifier.

5. The Number of Phases in a Simple Rectifier. The number of phases in a *simple single-way* rectifier is equal to the number of rectifying elements.

The number of phases in a *simple double-way* rectifier is equal to half the number of rectifying elements.

A double-way rectifier may have a primary-current wave shape and a d-c ripple voltage corresponding to a single-way rectifier having twice the phases of the double-way rectifier.

In describing a *simple rectifier*, three items of information are usually necessary and sufficient:

(*a*). The number of phases of the rectifier.

(*b*). Classification as either single way or double way.

(*c*). The transformer-circuit description if transformers are used.

Example: A three-phase single-way rectifier using delta zigzag wye transformers.

6. Multiple Rectifier. A multiple rectifier is one in which two or more similar simple rectifiers are connected in such a way that their direct currents add, but their d-c voltage ripples do not coincide. Interphase transformers are usually required between the component simple rectifiers in a multiple rectifier.

When two or more groups of rectifying elements operate so that their d-c currents add and their d-c voltage ripples coincide, the groups of rectifying elements are in parallel.

In describing a multiple rectifier, four items of information are usually given, and a fifth, the classification as single-way, is usually assumed. The information expressly stated is:

(*a*). The primary wave shape, or the number of phases in a simple single-way rectifier to give the same primary wave shape.

(*b*). The number of component simple rectifiers in the multiple rectifier.

(*c*). The number of phases in a component simple rectifier.

(*d*). The transformer-circuit description if transformers are used.

Example: a 12-phase quadruple wye (single-way) rectifier, using delta zigzag wye transformers.

7. Cascade Rectifier. A cascade rectifier is a rectifier in which two or more similar simple rectifiers are connected in such a way that their d-c voltages add.

8. Commutating Reactance. The commutating reactance is the reactance which effectively opposes normal currens transfer between rectifying elements which conduct consecutively.

In the actual rectifier circuit this reactance is usually distributed in various parts of the circuit; for example, the anode leads, the transformer windings, and the a-c supply system. In many cases these reactances may be considered as lumped in the transformer secondary.

9. Reactance Factor (Commutating-Reactance Factor). The commutating-reactance factor is the per-unit commutating reactance calculated on the arbitrary base of the rms value of the secondary line-to-neutral voltage divided by the direct current commutated.

Particular attention is called to the terms "double-way" rectifier and "single-way" rectifier. These terms are suggested to replace the terms "half-wave" and "full-wave" as frequently employed. There are two arguments against the old terms. In the first place, they have been used by two groups in different ways. For example, the circuit shown in Figure 1 is sometimes described as a "full-wave" circuit. It is also described as a "half-wave" circuit by a substantial group.

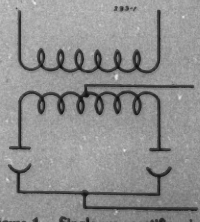

Figure 1. Single-way rectifier circuit

Paper 42-83, recommended by the AIEE committee on electrical machinery and joint subcommittee on electronics for presentation at the AIEE North Eastern District meeting, Schenectady, N. Y., April 29–May 1, 1942. Manuscript submitted February 17, 1942; made available for printing April 2, 1942.

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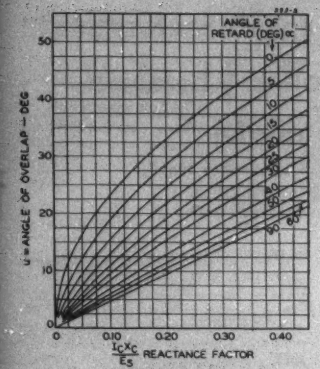

Figure 2. Angle of overlap—characteristic curves. $P = 3$

$$\cos(u+\alpha) = \cos\alpha - \frac{I_c X_c}{\sqrt{2}E_s \sin\frac{\pi}{p}}$$

when $\alpha = 0$

$$\cos u = 1 - \frac{I_c X_c}{\sqrt{2}E_s \sin\frac{\pi}{p}}$$

With this background of confusion a new term seems the only solution. A further objection to the terms "full-wave" and "half-wave" is the fact that they are accurately descriptive only in the case of 180-degree conduction, which is not widely used in power rectifiers. The terms "double-way" and "single-way" describe accurately the physical difference which separates the two classes of rectifiers and results in different general relations for several current and voltage ratios.

The "simple rectifier" is an essential

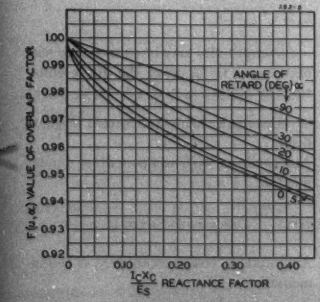

Figure 3. Overlap factor—characteristic curves. $C = 3$

$$F(u,\alpha) = \sqrt{1 - C(u,\alpha)}$$

when $\alpha = 0$

$$F(u) = \sqrt{1 - C(u)}$$

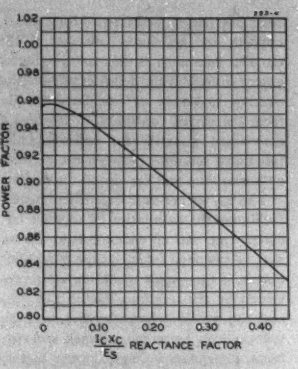

Figure 4. Power factor—characteristic curve for delta double-wye rectifier. $P = 3$, $C = 3$

$$PF = \frac{3}{\pi} \cdot \frac{1}{\sqrt{1 - 3K(u)}} \cdot \left(1 - \frac{E_x}{E_{do}}\right)$$

step in the development of the more complicated rectifier circuits, and it seems necessary to employ this term.

The definition of the number of phases as given is required if a general relation for the d-c voltage is to be employed. This definition is logical and consistent. Unfortunately the biphase rectifier as here defined has frequently been classed as a single-phase rectifier.

The "multiple rectifier" is here restricted to the case of several simple rectifiers operating in parallel in such a way that their d-c voltage ripples do not coincide. This is a unique arrangement in rectifier practice which improves the operation on both the a-c and d-c sides. Some name for this type of rectifier is needed.

The effect of commutating reactance in

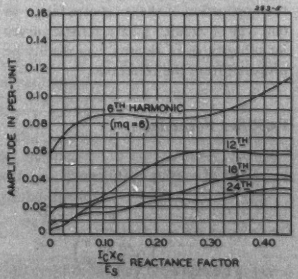

Figure 5. Amplitude of harmonic voltages in d-c voltage wave—characteristic curves. $q = 6$

$\alpha = 0$

$m = 1, 2, 3,$ and 4

Per-unit base is E_{do}

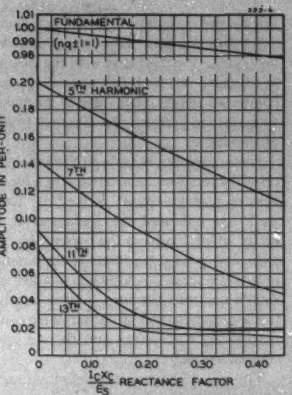

Figure 6. Amplitude of harmonic currents in a-c line current—characteristic curves. $q = 6$

$\alpha = 0$

$n = 0, 1, 2$

Per-unit base is amplitude of fundamental with no overlap

causing d-c voltage regulation is a source of much confusion. It is to be hoped that an exact definition of commutating reactance may help to dispel some of this confusion.

Reactance Factor

The methods employed in analyzing rectifier circuits and the formulas for rectifier-circuit characteristics have been quite thoroughly covered in the literature and are now well understood. However, no standard procedure has been devised for making the circuit calculations or presenting the calculated data, and as a result

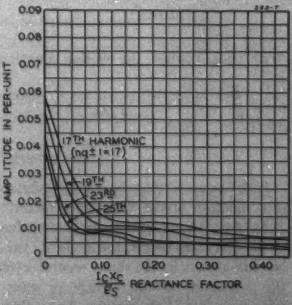

Figure 7. Amplitude of harmonic currents in a-c line current—characteristic curves. $q = 6$

$\alpha = 0$

$n = 3$ and 4

Per-unit base amplitude of fundamental with no overlap

the routine calculation of rectifier characteristics has been more laborious than necessary. Furthermore, with the lack of a standard method for presenting the calculated results, it is difficult to make comparisons between the different types of circuits.

Some attempts have been made to express the rectifier characteristics as a function of a single-circuit factor.[2-5] This work has indicated the usefulness of a factor which combines the current, reactance, and voltage constants of the circuit in a single quantity, although the use of such a quantity has been limited largely to the determination of the harmonic content of the d-c voltage and the a-c line current waves.

This paper proposes the definition and advocates the general use of a single factor of this kind for the purpose of simplifying the description and calculation of the operating conditions of any rectifier circuit. It is further proposed that this factor be known as the "reactance factor" and that it be the product of the direct current commutated I_c and the line-to-neutral commutating reactance X_c divided by the rms value of the transformer secondary line-to-neutral voltage E_s, that is, I_cX_c/E_s.

Circuit Analysis

The rectifier-circuit characteristics depend to a large degree upon the effect of reactance in causing an overlapping of the anode current waves The amount of overlapping is given by the well-known equation for the angle of overlap, which follows:

$$\cos u = 1 - \frac{I_cX_c}{\sqrt{2}E_s \sin \frac{\pi}{P}}$$

With phase control, the overlap equation is

$$\cos (u+\alpha) = \cos \alpha - \frac{I_cX_c}{\sqrt{2}E_s \sin \frac{\pi}{P}}$$

It will be noted that the angle of overlap is a function of the "reactance factor," I_cX_c/E_s. Therefore, for any given value of the reactance factor, the angle of overlap will always be the same, regardless of the particular current, voltage, or reactance constants of the circuit. From this, it follows that if the magnitudes of the current and voltage waves in the rectifier circuit are expressed in per-unit quantities upon a suitable base, the configuration of the current and voltage waves will be the same for any given value of the reactance factor, regardless of the voltage, current, and reactance constants of the circuit. Inasmuch as the reactance factor enters directly in the determination of the overlap, and may be calculated readily from the circuit constants, it provides a convenient quantity for indicating the functional relations between the rectifier characteristics and the circuit constants.

The use of per-unit quantities greatly facilitates the calculation of rectifier circuits. One set of characteristic curves may be prepared for each type of rectifier circuit, if the circuit constants are represented by the reactance factor I_cX_c/E_s and the rectifier characteristics, such as voltage drop, harmonic voltages, and currents, interphase voltages, power factor, and so forth are expressed in per unit. Using such a procedure, it is possible to reduce rectifier calculation to a minimum, calculating the characteristic curves only once. For example, to obtain information regarding any specific circuit, its reactance factor is first calculated from the circuit constants. Reference is then made to the characteristic curves, and the corresponding per-unit value of the desired characteristic determined. The actual numerical value may be calculated by multiplying this per-unit value by the base value. The theoretical d-c voltage E_{do} and the rms value of the transformer secondary line-to-neutral voltage E_s are convenient bases for calculation of per-unit voltages, while the direct current commutated I_c and the theoretical a-c line current I_L are convenient bases for per-unit currents.

The list of rectifier formulas and the accompanying curves show a few of the more commonly used rectifier characteristics, with their equations reduced to their simplest form in terms of reactance factor and the calculated values given on a per-unit basis. These curves illustrate the application of the reactance factor to one type of circuit. Characteristic curves for other types of circuits may readily be prepared from the equations.

Rectifier Formulas

1. Angle of overlap u (Figure 2)

$$\cos (u+\alpha) = \cos \alpha - \frac{1}{\left(\sqrt{2} \sin \frac{\pi}{P}\right)} \frac{I_cX_c}{E_s}$$

(with no phase control)

$$\cos u = 1 - \frac{1}{\left(\sqrt{2} \sin \frac{\pi}{P}\right)} \cdot \frac{I_cX_c}{E_s}$$

2. Overlap factor $\sqrt{1-cf(u,\alpha)}$ (Figure 3)

where

$$f(u,\alpha) = \frac{1}{2\pi}\left[\frac{\sin u(2+\cos(u+2\alpha)) - u(1+2\cos\alpha\cos(u+\alpha))}{(\cos\alpha - \cos(u+\alpha))^2}\right]$$

3. D-c voltage drop E_X

$$E_X = \frac{I_cX_cP}{2\pi}$$

(in per unit on base E_{do})

$$\frac{E_X}{E_{do}} = \frac{1}{2\sqrt{2}\sin\frac{\pi}{P}} \cdot \frac{I_cX_c}{E_s}$$

4. Power factor PF (Figure 4)

$$PF = K \cdot \frac{\left(\cos\alpha - \frac{E_X}{E_{do}}\right)}{\sqrt{1-cf(u,\alpha)}}$$

5. Harmonics in d-c voltage (Figure 5)

Amplitude of sine components

$$a_m = \frac{E_{do}}{2}\cos m\pi \times \left[\frac{\sin(mq+1)(u+\alpha)+\sin(mq+1)\alpha}{mq+1} - \frac{\sin(mq-1)(u+\alpha)+\sin(mq-1)\alpha}{mq-1}\right]$$

Amplitude of cosine components

$$b_m = \frac{E_{do}}{2}\cos m\pi \times \left[\frac{\cos(mq+1)(u+\alpha)+\cos(mq+1)\alpha}{mq+1} - \frac{\cos(mq-1)(u+\alpha)+\cos(mq-1)\alpha}{mq-1}\right]$$

Amplitude of resultant

$$h_m = \sqrt{a_m^2+b_m^2}$$

All amplitudes may be expressed in per-unit values by dividing the above equations by E_{do}.

6. Harmonics in a-c line current (Figures 6 and 7)

Amplitude of sine component of fundamental

$$a_1 = \frac{\sqrt{3}I}{\pi}[\cos\alpha + \cos(u+\alpha)]$$

Amplitude of cosine component of fundamental

$$b_1 = \frac{\sqrt{3}I}{\pi}\left[\frac{1/2\sin(2u+2\alpha) - 1/2\sin 2\alpha - u}{\cos\alpha - \cos(u+\alpha)}\right]$$

Amplitude of the resultant of the fundamental components

$$h_1 = \sqrt{a_1^2+b_1^2}$$

Temperature-Aging Tests on Class-A-Insulated Fractional-Horsepower Motor Stators

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Synopsis: Temperature-aging data are presented on class-*A*-insulated fractional-horsepower motor stators, determined at 200, 160, and 135 degrees centigrade. Of particular interest is the relative aging time to failure at the different temperatures and the resultant temperature-aging curve. This curve shows a slope of 10 to 15 degrees centigrade increase in temperature to halve the aging time to failure in the temperature range covered, 135 to 200 degrees centigrade.

THE question of the rate at which motor insulation ages due to the temperature to which it is exposed was brought actively to the fore several years ago[1-7] by discussion concerning methods of rating machines whose normal load cycle was intermittent. Many such are encountered in air conditioning, welding, and other applications governed by automatic controls. In such intermittent operation the temperature of the motor varies, depending upon the load cycle to which it is subjected. It is desired that the effect of such temperature variation be not greater, as regards aging of the insulation, than the continuous temperature for which the motor was designed. In order to know this, it is necessary to have a knowledge of the rate of aging at different temperatures. This is really a demand for a knowledge of the aging temperature characteristic of insulation such as is shown in Figure 6.

To obtain such a temperature-aging characteristic, we must carry out our tests at more elevated temperatures, starting perhaps much higher than those in which we are interested, and, through simultaneously started tests at a number of temperatures between this and our operating range, gradually accumulate the data from which our life-temperature curve may be drawn as far down toward the operating range as the results lead us to continue.

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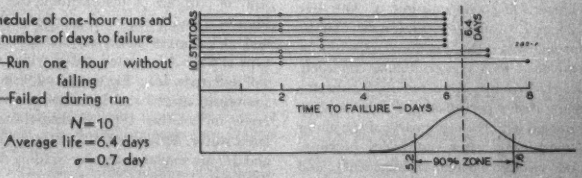

Figure 1. 200 degrees centigrade aging tests on class-*A*-insulated stators, type *N*

Method of Test

The question of type of test must next be answered. The actual operation of motors of even moderate size, under load in numbers sufficient to yield statistically reliable results, becomes costly and subject to a number of causes of motor failure, such as bearings, starting switches, and so forth.

If we wish to study the influence of temperature on the insulation alone, it is desirable that the tests be conducted so that they are not complicated by these additional sources of failure which arise in an actual running test.

In the past[1] this has been attempted by constructing samples of a variety of kinds, aging them at a number of selected test temperatures, and periodically making a number of tests and measurements of properties, usually destructive. The study of these results enabled one to plot the deterioration of these arbitrarily selected properties in terms of time and temperature, and, with some approximation, to arrive at a temperature-aging relation. One of the present authors gave the results of such a study several years ago.[1] Such tests involve doing things to the sample of insulation such as breaking it, bending it, or otherwise maltreating it. Since service does not involve these factors in similar kind or degree, one usually finished his labors with a curiosity as to

Amplitude of sine component of higher harmonics

$$a_m=\frac{4I}{\pi}\cdot\frac{\sin(m\pi/3)}{m(m^2-1)(\cos\alpha-\cos(u+\alpha))}\times$$
$$[\cos\alpha\cos m\alpha-\cos(u+\alpha)\cos m(u+\alpha)+$$
$$m\sin\alpha\sin m\alpha-m\sin(u+\alpha)\sin m(u+\alpha)]$$

Amplitude of cosine component of higher harmonics

$$b_m=\frac{4I}{\pi}\cdot\frac{\sin(m\pi/3)}{m(m^2-1)(\cos\alpha-\cos(u+\alpha))}\times$$
$$[\cos\alpha\sin m\alpha-\cos(u+\alpha)\sin m(u+\alpha)-$$
$$m\sin\alpha\cos m\alpha+m\sin(u+\alpha)\cos m(u+\alpha)]$$

Amplitude of the resultant for each of the higher harmonics

$$h_m=\sqrt{a_m^2+b_m^2}$$

The amplitude of the fundamental of the theoretical line current wave, that is, with no phase control ($\alpha=0$) and no overlap ($u=0$) is

$$a_1=\frac{2\sqrt{3}I}{\pi}\qquad b_1=0$$

All amplitudes may be expressed in per-unit values using the amplitude of the fundamental with no phase control and no overlap as a base by dividing the above equations by $\frac{2\sqrt{3}I}{\pi}$.

Refer to references 2, 3, and 5 for symbols not defined in text.

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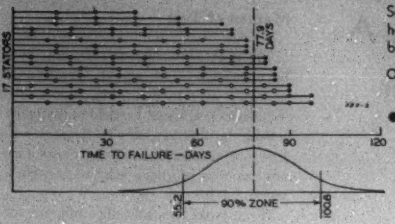


Schedule of one-hour runs and number of days to failure

O—Run one hour without failing

●—Failed during run

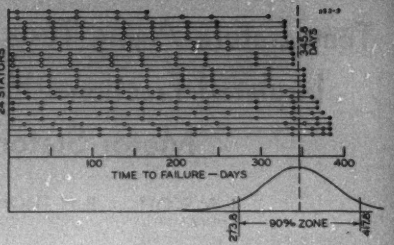


Figure 2. 160 degrees centigrade aging tests on class-A-insulated stators, type N

$N = 17$ Average life = 77.9 days
$\sigma = 13.8$ days

Figure 3. 135 degrees centigrade aging tests on class-A-insulated stators, type N

$N = 24$ Average life = 345.8 days
$\sigma = 43.7$

what the actual service life at the test temperature might have been.

The present tests followed a course intermediate between the two alternatives outlined above, with the full recognition that the results could not be directly used to predict motor life in service, but hopeful that some light might be thrown on the temperature-aging relationship, even though only in a proportional manner. Recognizing that the completely wound and insulated stators of fractional-horsepower induction motors are both low cost and convenient specimens, and ones which represent a very widely used kind of class-A insulation, it was decided to use these for the test specimens. Exploratory tests and previous experience led us to choose aging temperatures of 200, 160, 135, and 115 degrees centigrade. To determine when these stators had temperature-aged to a nonserviceable condition, selected groups were removed from the aging ovens periodically and in turn assembled with the other parts of the motor (squirrel-cage rotor, end shields, bearings, and suitable switch arrangement), and subjected to an actual and severe operating test. This test consisted of a one-hour period of operation at no load, and approximately full-load heating, with a sudden and complete reversal in rotation from full speed every two minutes. On successful completion of this operation test the stators were restored to the aging oven for a continuation of the aging test. When the aging had proceeded to the point at which failures began to be experienced, tests were made more often. Proceeding in this way, an aging time was determined which reduced the insulation to such a state of embrittlement and crumbliness that physical separation was no longer afforded the conductors, and short circuits, or grounds, resulted. This aging time we call the time to failure of the insulation at that temperature for the specific conditions of the test.

Results

Figures 1, 2, and 3 show the results which have been obtained to date at 200, 160, and 135 degrees centigrade for one type of class-A-insulated stator, which we will, for purposes of identification, call *N*. Figures 4 and 5 show the results at 200 and 160 degrees centigrade on another type of class-A-insulated stator, which we will designate *M*1. Figures 8 and 9 show the results at 200 and 160 degrees centigrade on another type of class-A-insulated stator, designated *M*2. Stators *M*1 and *M*2 are similar except for winding differences.

These figures are similarly drawn and show:

1. The time for each stator at which test runs were made.
2. The time of the test run at which failure occurred; this is called the "time to failure" at that stator.
3. The average time to failure of the group of stators tested at each temperature.
4. The root-mean-square deviation, σ, of the time to failure of the individual stators from that of the group average. This is the customary statistical measure of the dispersion of test results.
5. A normal distribution curve calculated from the root-mean-square deviation, σ.
6. The width of the 90 per cent zone or the time interval during which approximately 90 per cent of all the motors fail. This total width is $3.29\ \sigma$.

We have purposely placed emphasis in this presentation on the normal variation in the life span, here at least 2 to 1. Life is inherently a variable thing, and engineers must accept this in their motors as they do in their own lives.

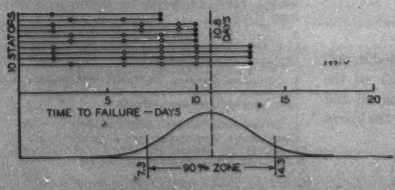
Having determined the "time to failure" of these three types of stators at several temperatures, the data can now be plotted in the form of the temperature-aging characteristic listed at the start as the object of our investigation. The average times to failure at the several test temperatures are plotted opposite each temperature. Figure 6 is such a curve for the type *N* stators from 200 down to 135 degrees centigrade (with another point at 115 degrees centigrade due to come at some time in the future). Figure 7 is for the type *M*1 stators, covering only the two temperatures—200 and 160 degrees

Figure 4. 200 degrees centigrade aging tests on class-A-insulated stators, type M1

$N = 10$ Average life = 10.8 days
$\sigma = 2.1$ days

Figure 5. 160 degrees centigrade aging tests on class-A-insulated stators, type M1

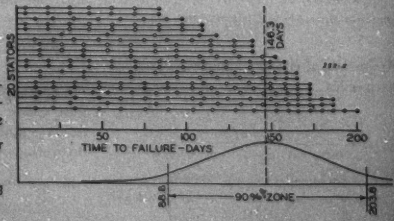
$N = 20$ Average life = 146.3 days
$\sigma = 35.0$ days



Schedule of one-hour runs and number of days to failure

O—Run one hour without failing

●—Failed during run



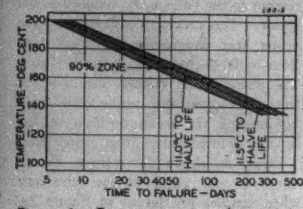


Figure 6. Temperature-aging characteristic, class-A-insulated stators, Type N

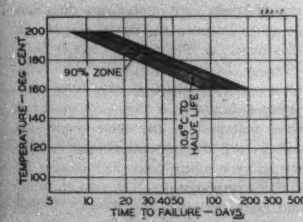


Figure 7. Temperature-aging characteristic, class-A-insulated stators, type M1

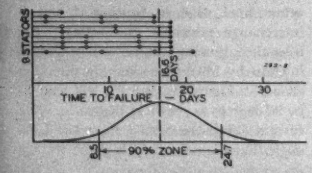


Figure 8. 200 degrees centigrade aging tests on class-A-insulated stators, type M2

Schedule of one-hour runs and number of days to failure

O—Run one hour without failing

●—Failed during run

N=9 Average life = 16.6 days

σ = 4.9 days

centigrade, and similarly Figure 10 for the type *M*2 stator.

At the present time after 660 days elapsed time since starting, the tests on the *M*1 stators at 135 degrees centigrade have yielded five failures in 30 stators, 17 per cent. The 135 degrees centigrade point may thus be seen as lining up fairly well with the trend outlined by the two higher temperatures.

Conclusions

A method of studying the temperature-aging characteristics of class-*A*-insulated

Figure 9. 160 degrees centigrade aging tests on class-A-insulated stators, type M2

Schedule of one-hour runs and number of days to failure

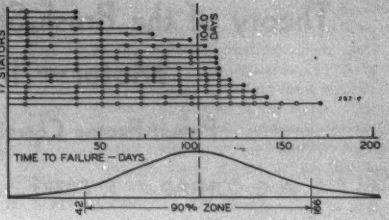
O—Run one hour without failing

●—Failed during run

N= 17

Average life = 104.0 days

σ = 37.5 days



fractional-horsepower motor stators has been presented. The results available to date cover the tests made at 200 and 160 degrees centigrade and some results at 135 degrees centigrade. The tests are being continued at lower temperatures so that this paper is in the nature of a progress report. The following general statements can be made as to the comparative effects of various temperatures.

1. Below 200 degrees centigrade there is no temperature which, if exceeded, causes an abrupt failure of the insulation; that is, the temperature-aging curve of the insulation of these motors is uniform and continuous.

2. Operation at higher temperatures than normal results in a shortening of the time to failure of the insulation. Figures 6 and 7 agree that a temperature increment of 10 or 11 degrees centigrade is required to cut the time to failure of the stators in half. This agrees nicely (without the implications of accuracy) with the eight-degree value widely used for transformer insulations.[8,9] Figure 8 gives a corresponding temperature increment of 15 degrees centigrade. The value has not yet been established below the 135 degrees centigrade range in these tests.

3. The width of the "90 per cent zone" (or zone containing 90 per cent of the values) is shown to emphasize the normal spread of results. Its width is obtained from Figures 1 through 5.

4. The normal time to failure of the insulation of duplicate specimens has a spread of 2 to 1.

It will be noted that no conclusion as to the probable actual operating life of the insulation for any given temperature has been drawn from these tests. This is for the reason that, as pointed out previously, the tests have been made in such a manner as to single out the effects due to temperature and to exclude other effects which would be met with in actual operation of the motor in service. This might include the effect of moisture, the effect of dirt, oil, or various gases in the atmosphere, the effect of vibration which might

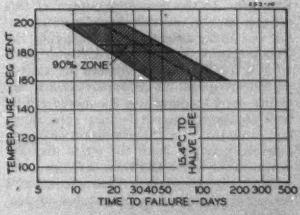


Figure 10. Temperature-aging characteristic, class-A-insulated stators, type M2

be encountered with various types of loads, changes in ambient temperature, intermittent loading, and other factors, some of which may tend to increase and others to decrease the life in actual operation.

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Theory of the Brush-Shifting A-C Motor—III

Power-Factor Correction

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Synopsis: In the preceding papers[1] of this series a method was described for determining the circle diagram and predicting the characteristics for the brush-shifting motor as it is used when the brushes are shifted to control speed. This paper extends the earlier work to show how the motor can be used to correct power factor. The range and limitations for this condition of operation are revealed from the circle diagram of the motor which has been developed and verified experimentally. Characteristics of the motor when used in this manner are presented.

Brush Settings for Power-Factor Correction

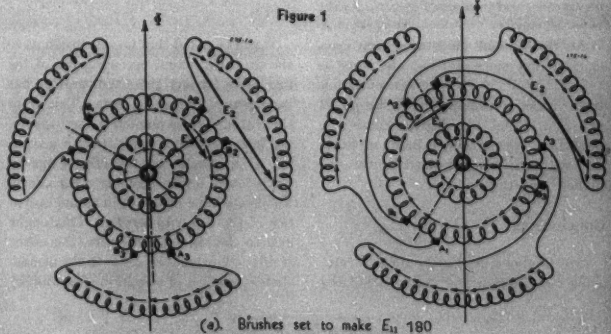
UNDER normal operation of the brush-shifting a-c motor, the two sets of brushes which carry the secondary current of the stator coils are coupled mechanically so that one set of brushes cannot be moved without a corresponding motion of the other in the opposite direction. Thus, the voltage introduced in the secondary circuit from the commutator, while it may vary in magnitude with speed adjustment, does not vary in phase relative to the voltage induced in the stator winding. Figure 1a is a schematic diagram of a two-pole, three-phase brush-shifting motor. The horizontal projections of the vectors represent the instantaneous voltages induced in the adjacent coils. The flux, ϕ, rotates at slip speed, say clockwise, relative to the stator. Brushes A_1, A_2, and A_3 are mounted rigidly on an adjustable frame so that a motion of the frame will move them all through the same angle; brushes B_1, B_2, and B_3 are mounted similarly and also move in unison. These two frames are coupled mechanically so that when making speed adjustments, the brushes are always equal distances from the center lines drawn between them. The points of maximum and minimum potential about the commutator rotate with the field relative to the stator so that the voltages at the brush pairs are at slip frequency. If the center lines drawn midway between the brushes A_1 and B_1, A_2 and B_2, and so on, remain fixed relative to the stator, the voltages collected from the commutator are fixed in phase relative to the induced voltage in the stator. The magnitude of this voltage, E_{11}, will vary with the degree of separation of the brushes but is approximately independent of speed for a given primary voltage. Interchanging the positions of the brushes A_1 to B_1, B_1 to A_1, and so on, will change the phase by 180 degrees, that is, reverse the polarity of the commutator voltage, E_{11}.

If the coupling between the frames supporting each set of brushes is removed, either set can be moved in either direction independently of the other. The various possible brush settings provide the motor with an extremely wide range of characteristics. If the flux, ϕ, is rotating clockwise relative to the stator, and the two frames are moved opposite to the direction of rotation of the flux with respect to the stator by 90 degrees from the position shown in Figure 1a (see Figure 1b), the voltage, E_{11}, will be advanced by 90 degrees inphase with respect to the voltage, E_2, induced in the stator. This procedure will advance the center lines designating the brush positions by 90 degrees relative to the stator. The phase of the voltage, E_{11}, collected from the commutator can be varied only by altering the mean position of the brushes as indicated by these center lines.

Figure 2a shows the voltage, E_2, induced in one phase of the secondary when brushes are set as in Figure 1a, that is, when E_2 is in opposition to E_{11}. Figure 2b shows what occurs when both sets of brushes are rotated in a direction so as to advance E_{11} by 90 degrees as illustrated in Figure 1b. Since both voltages, E_2 and E_{11}, are in series, and force currents through the same impedance, I_2 and I_{11} of Figure 2b must lag their voltages by the same angle. I_2 and I_{11} are the currents flowing in the secondary resulting from the voltages E_2 and E_{11} respectively. The two currents and their circle loci are shown. If the center lines are allowed to remain in their new positions of Figure 1b, and the two sets of brushes are moved across the center lines, that is, brushes A and B interchange positions, the voltage, E_{11}, from the adjusting winding will be shifted in phase by 180 degrees from the direction shown in Figure 2b, and E_{11} will lead E_2 by 90 degrees as shown in Figure 2c. The current I_2 lags the voltage E_2 by the same angle that the current I_{11} lags the voltage E_{11}.

If the motor is designed so that the effective number of series turns in the adjusting winding is half the effective number of stator turns, the largest value of the voltage, E_{11}, is half the stator voltage, E_2 at standstill. If in Figures 2a, 2b, and 2c, the brushes of each phase are spaced 180 electrical degrees apart on the commutator, E_{11} will have its largest

Figure 1



(a). Brushes set to make E_{11} 180 degrees out of phase with E_2
(b). Brushes shifted to make E_{11} lead E_2 by 90 degrees

(a) (b)

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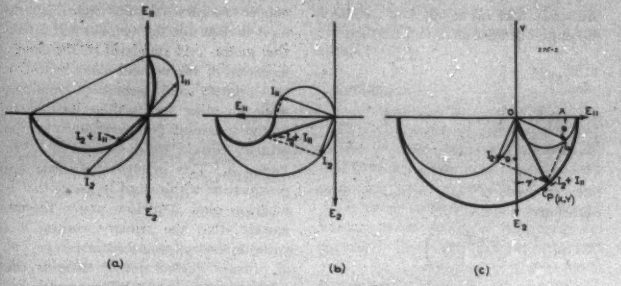


(a). E_{II} 180 degrees out of phase with E_2 (b). E_{II} lagging E_2 by 90 degrees (c). E_{II} leading E_2 by 90 degrees

Figure 2. Vector diagrams of secondary voltages and currents when brushes are set to make

value. The largest value of I_{II} (its value at synchronous speed) and the largest value of I_2 are as determined in part I of this series. The resultant secondary current is the vector sum of I_2 and I_{II}, and, as is shown in Figures 2b and 2c, this current is never zero whenever E_{II} has a quadrature component relative to E_2. The locus of the extremity of the vector representing the sum of I_2 and I_{II} is derived in appendix A, and is found to be another circle shown in wide lines in Figures 2b and 2c.

In Figure 2b it is evident that the total current flowing in the secondary lags the voltage, E_2, induced in the secondary by a relatively large angle at all times. In Figure 2c the total secondary current leads the voltage, E_2, over a considerable portion of the circle. These features enable the machine to generate power at a lagging power factor when used as a generator excited from a synchronous source. Furthermore it can supply these lagging loads over a wide range of speeds. This paper is primarily concerned with power-factor correction, and, therefore, will deal only with conditions illustrated in Figure 2c, rather than those of Figure 2b.

Primary Currents With Power-Factor Correction

The phase current in the primary of this motor can be determined from a knowledge of the magnetomotive forces in the adjusting winding and the stator winding for different values of slip. For each current I_2 and I_{II}, shown in Figure 2c, there is a corresponding magnetomotive force produced in each of these windings. The magnetomotive force produced by the current I_{II}, of Figure 2c, in the stator is represented by the vector oa of Figure 3. Likewise, the magnetomotive force produced by the current I_2 of Figure 2c in the stator is represented by the vector ob of Figure 3. The total magnetomotive force produced in the stator by the currents I_2 and I_{II} is therefore the vector oc of Figure 3, which is the sum of oa and ob. The locus of this stator magnetomotive force, oc, is defined by the circle dce. With this particular brush setting on a three-phase motor, there is a magnetomotive force produced by these same currents, I_2 and I_{II}, flowing in the adjusting windings. This magnetomotive force is 90 degrees behind the magnetomotive force that these currents produce by flowing in the stator. The vector oc' therefore represents the adjusting winding magnetomotive force when the stator magnetomotive force is oc. The locus of the vector oc' is the circle $d'c'e'$. The proportions of this circle are such that

$$\frac{oc'}{oc} = \frac{od'}{od} = \frac{oe'}{oe} = \frac{N_{AW}}{N_2}$$

With the brushes set as described here, motor action results only at speeds below synchronism. For such speeds, magnetomotive forces in the stator and adjusting windings are cancelled by equal and opposite magnetomotive forces in the primary. In Figure 3, the stator magnetomotive force co is counteracted by the component primary magnetomotive force oc'', and the adjusting winding magnetomotive force oc' is counteracted by the component primary magnetomotive force oc'''. The total magnetomotive force of the primary that is necessary to counteract the magnetomotive forces of the adjusting winding and the stator is the sum of oc'' and oc''', which is oc''''. The locus of the extremity of this vector oc'''' is defined by the circle $d''''c''''e''''$. The primary magnetomotive force must be produced by a current which is proportional to and in phase with oc''''. In Figure 3 this current is shown as the vector I_{1L}. The locus of I_{1L} is another circle having a center coincident with the center of the circle $d''''c''''e''''$. The locus of the primary current can be obtained by adding to this current I_{1L}, the current po. The current po is the no-load current taken by the motor when the brushes are set to make

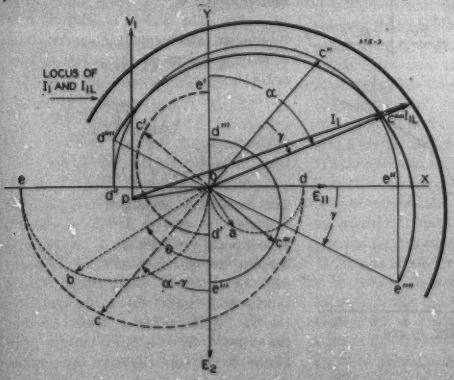


Figure 3. Vector diagram of motor when used to correct power factor

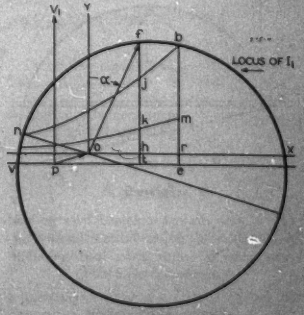


Figure 4. Characteristic vector diagram of motor (primary), E_{II} 90 degrees ahead of E_2

E_{11} zero. The total current taken by the primary, shown on this diagram, is the vector I_1, and the locus of its extremity with respect to the point p is defined by the same circle that defines I_{1L}. This circle has a diameter passing through the point o at an angle γ, the tangent of which is equal to the ratio of the effective number of turns in the adjusting winding between brushes to the effective number of stator turns, N_{AW}/N_2.

A change in the brush setting will change the total resistance and reactance of the total secondary circuit and, consequently, change the diameters of both the circle loci of I_{11} and I_2. With the brushes set to obtain the characteristics illustrated in Figure 3, the motor will take a leading current, I_1, with respect to the impressed voltage, V_1 over a considerable range of loads. For such conditions of load, it can be used to correct the power factor of the line supplying the motor.

Determination of Characteristics When Motor Is Used to Correct Power Factor

On the basis of the theory and assumptions of part I of this series, it was shown that the currents I_2 and I_{11} could be expressed thus:

$$I_2 = \frac{{}_{22}E_2 S}{\sqrt{(R_2+R_{AW})^2+S^2({}_{22}X_2+{}_{22}X_{AW})^2}} \quad (1)$$

$$I_{11} = \frac{E_{11}}{\sqrt{(R_2+R_{AW})^2+S^2({}_{22}X_2+{}_{22}X_{AW})^2}} \quad (2)$$

Therefore

$$\frac{I_2}{I_{11}} = \frac{{}_{22}E_2 S}{E_{11}} \quad (3)$$

If the brushes supplying each stator phase are set so that E_{11} equals half ${}_{22}E_2$, as is illustrated in Figures 2b and 2c, then

$$\frac{{}_{22}E_2 S}{E_{11}} = 2S \quad (4)$$

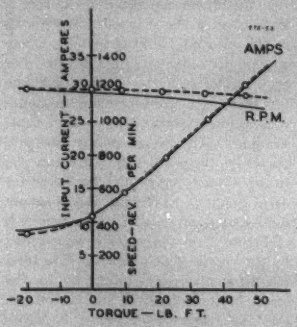
At standstill S equals one, and

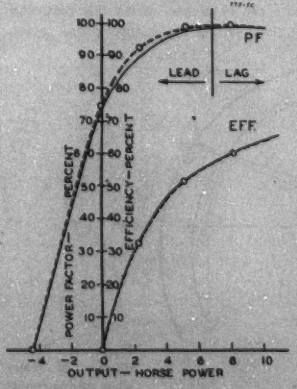
$$\frac{I_2}{I_{11}} = 2 \quad (5)$$

Since the ratio of I_{2max} to I_{11max} is, from equations 1 and 2,

$$\frac{I_{2max}}{I_{11max}} = \frac{{}_{22}E_2}{E_{11}}\left(\frac{R_2+R_{AW}}{{}_{22}X_2+{}_{22}X_{AW}}\right) \quad (6)$$

a knowledge of the ratio of R_2+R_{AW} to ${}_{22}X_2+{}_{22}X_{AW}$ is all that is required to determine the diameters of the two component circles, I_2 and I_{11}, and from them the resultant circle defining the extremity of the primary current vector as described above. At synchronous speed I_2 is zero and I_{11} is maximum. If the primary currents for standstill and for some other speed are known, it is possible to determine the characteristic





copper loss curves for the circle diagrams as it is done for the two-element induction motor. At standstill all the energy in excess of the no-load losses is lost in the primary and secondary windings, while for other speeds these losses vary as the square of that component of the primary current which is labelled I_{1L} in Figure 3. This involves the same approximation with regard to losses that is made in plain induction motor theory; namely, that the primary copper loss varies as the square of the load component of primary current rather than as the total primary current. The error introduced by this approximation in the two-element induction motor is negligible. The error due to this approximation is somewhat larger in this motor than in the two-element motor, but not so large as to invalidate the method.

The characteristic copper loss curve, bjn, is shown in Figure 4. The point, m, determined by measurement of primary resistance divides rb into components proportional to the primary and secondary losses. The current pb produces a primary loss which is represented by mr. The loss for any primary current, pf, can be represented by kh which in turn can be determined by the relationship

$$kh = mr\left(\frac{pf}{pb}\right)^2$$

The secondary copper loss represented by jk can be found in similar fashion.

The slip is a function of the angle $(\alpha-\gamma)$ by which I_2+I_{11} lags E_2. This is also the angle between the vector oc in Figure 3, representing the magnetomotive force due to I_2+I_{11} in the stator windings, and the vector labelled E_2, the voltage induced in the stator by the air-gap flux. The angle α is the phase angle between the voltage V_1 and the primary-current component I_{1L}, or the magnetomotive force oc''''. This angle varies with slip. The angle γ is determined by its tangent which equals N_{AW}/N_2; thus, γ is independent of slip. The relation between slip and $(\alpha-\gamma)$ is given by

$$\tan(\alpha-\gamma) = \frac{1-\left(\frac{1}{\tan\gamma}\right)^2\left(\frac{I_{11max}}{I_{2max}}\right)S^2}{\left(\frac{1}{\tan\gamma}\right)\left(\frac{I_{11max}}{I_{2max}}+1\right)S} \quad (7)$$

This equation is developed in appendix B and may be used to determine the slip at any point f (see Figure 4) on the circle defining the extremity of I_1. The speed may be obtained, since speed equals synchronous speed times the quantity, $(1-S)$. If the motor is loaded so that the primary draws a phase current pf in Figure 4, the slip will have some value,

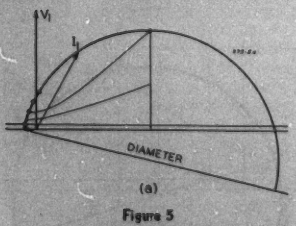


Figure 5

(a). Circle diagram obtained from no-load tests. Encircled points indicate primary currents taken by motor under load conditions (determined by loading)

(b) and (c). o - - - o - - - o Characteristics obtained by loading

——— Characteristics predicted from the circle diagram

S, corresponding to the point, f, and can be determined from measurements of α and equation 7.

If the impressed voltage per phase is represented by V_1, then for the input current, ff:

(1) Input $= (ff)\,V_1$ watts per phase
(2) Output $= (jf)\,V_1$ watts per phase
(3) Iron loss, friction, and windage $= (ih)\,V_1$ watts per phase
(4) Primary copper loss $= (hk)\,V_1$ watts per phase
(5) Copper loss of stator and adjusting winding $= (kj)\,V_1$ watts per phase
(6) Efficiency $= \frac{jf}{ff}$ times 100 per cent
(7) The slip is determined by the angle between of and V_1 (or between of and oy) using the equation (7)
(8) Speed $= (1-\text{slip})$ (synchronous speed in rpm) in rpm
(9) Torque $=$
$$\frac{(jf)\,V_1 \text{ (number of phases) } 33{,}000}{2\pi \text{ (speed in rpm) } 746} \text{ in pound-feet}$$

The output torque is zero at the point n in Figure 4. For slips less than that at n, power must be supplied to the machine through the shaft. At the point v, slightly above synchronous speed, all the power into the machine comes by way of the shaft.

Results of Test With Leading Commutator Voltage

In order to check the validity of the foregoing theory, a test was made on a General Electric BTA, 550–1,650-rpm. 4.17–12.5-horsepower, six-pole, 60-cycle motor. With the brushes set so that the commutator voltage was ahead of the induced voltage of the stator by 90 degrees, the gap between brushes was fixed so that the commutator voltage was 7.8 per cent of the stator voltage at standstill. The results of the load test and the blocked rotor test are indicated by the encircled points on the circle diagram of Figure 5a. The theoretical primary-current circle locus was determined from three no-load readings as described in parts I and II of this series. It is observed that the diameter of the circle lies beneath the horizontal chord by an angle of approximately ten degrees. Only about five degrees of this shift is accounted for by γ (the shift caused by the magnetomotive force of the adjusting winding). The remainder can be attributed directly to the leakage reactance of the primary circuit which, with high current values, causes the induced voltage, E_2, in the secondary to lag the primary voltage. Figure 5 shows the results predicted theoretically in comparison with the experimentally determined results.

Conclusions

The advantages of power-factor correction on a line supplying a motor are well-known. Advantages of power-factor correction to the motor itself result only when these corrections increase the efficiency of the motor or its horsepower capacity. The effect of power-factor correction on the efficiency of this motor is illustrated in Figure 6. Each of the efficiency curves shown here was obtained by a load test with brush settings that provided synchronous speed at no load.

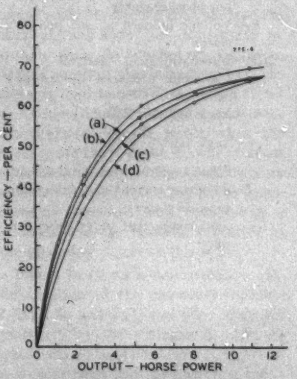


Figure 6. Efficiency as affected by power-factor correction

Brushes separated
(a). 0 electrical degrees
(b). 6 electrical degrees
(c). 12 electrical degrees
(d). 18 electrical degrees

It is evident that the addition of a small value of E_{11} (two per cent of its maximum value, that is, a brush separation of approximately five electrical degrees) to improve power factor will increase the efficiency only slightly. Further increases in E_{11} will cause excessive secondary currents and reduce the efficiency. It is evident from the theory developed here that if the primary exciting current is to be reduced the secondary must carry an additional exciting current to compensate for the reduction in the primary. Maximum efficiency for a given load will occur when the voltage E_{11} is adjusted so as to make the total copper losses in the motor a minimum. Any exciting current flowing in the secondary must be supplied through the commutator. For some conditions of load this additional current will cause poor commutation. Thus there is little to be gained from standpoint of the motor by setting its brushes to improve its power factor beyond the values obtained when E_{11} is made opposite to E_2.

From information revealed in Figure 5 it is quite evident that the motor can be adjusted to draw various amounts of leading current. This feature provides the possibility of improving the regulation and efficiency of the line supplying the motor. These curves of Figure 5 also show the relative high power factor obtainable on the brush-shifting motor as compared with the ordinary well-known two-element induction motor.

Appendix A

It can be shown that the locus of the sum of I_2 and I_{11} is a circle as follows:

The line OP of Figure 2c indicates the current vector representing the sum of I_2 and I_{11}. Let x equal the horizontal component of OP, and y equal the vertical component of OP. Since I_2 and I_{11} are always at right angles

$$OP^2 = I_2^2 + I_{11}^2$$
$$\text{or } OP^2 = I_2^2 + I_{11}^2 I_{2\max} I_{11\max} - I_{2\max} I_{11\max}(\sin^2\theta + \cos^2\theta)$$
But $I_2 = I_{2\max}\sin\theta$
$I_{11} = I_{11\max}\cos\theta$
$$OP^2 = I_2 I_{2\max}\sin\theta + I_{11} I_{11\max}\cos\theta + I_{2\max} I_{11\max} - I_{2\max} I_{11}\cos\theta - I_{11\max} I_2\sin\theta$$
$$OP^2 = I_{2\max}(I_2\sin\theta - I_{11}\cos\theta) - I_{11\max}(I_2\sin\theta - I_{11}\cos\theta) + I_{2\max} I_{11\max}$$
$$OP^2 = (I_{11\max} - I_{2\max})(I_{11}\cos\theta - I_2\sin\theta) + I_{2\max} I_{11\max}$$
but $x = I_{11}\cos\theta - I_2\sin\theta$
and $OP^2 = x^2 + y^2$
$$x^2 + y^2 = (I_{11\max} - I_{2\max})x + I_{2\max} I_{11\max}$$
$$y^2 + x^2 + x(I_{2\max} - I_{11\max}) + \frac{(I_{2\max} - I_{11\max})^2}{4} = I_{2\max} I_{11\max} + \frac{(I_{2\max} - I_{11\max})^2}{4}$$
$$y^2 + \left(x + \frac{I_{2\max} - I_{11\max}}{2}\right)^2 = \left(\frac{I_{2\max} + I_{11\max}}{2}\right)^2$$

This is the equation of a circle of radius $(I_{2\max} + I_{11\max}/2)$ with its center at $x = -1/2(I_{2\max} - I_{11\max})$ and $y = 0$. A similar method may be used to show that the locus of P in Figure 2b is also a circle.

Appendix B

In order to establish equation 7, it is necessary to refer to Figure 3. In this figure $(\alpha - \gamma)$ is the angle by which oc lags E_2. The vector oc represents the magnetomotive force produced in the stator by $I_2 + I_{11}$. The magnetomotive forces produced in the stator by I_2 and I_{11} separately are ob and oa respectively. The currents I_{11}, I_2, and

I_2+I_{11} with proper change in scale could be represented by oa, ob, and oc. If this is done, and if the point c is determined by the rectangular co-ordinates x and y, then

$$\tan(\alpha-\gamma)=-\frac{x}{y}$$

Since oa now represents I_{2max} and od represents I_{11max}, if θ is the power factor angle of the secondary circuit:

$$I_2=I_{2max}\sin\theta$$
$$I_{11}=I_{11max}\cos\theta$$

In Figure 3

$$x=I_2\sin\theta-I_{11}\cos\theta$$
$$y=I_2\cos\theta+I_{11}\sin\theta$$

so

$$\tan(\alpha-\gamma)=-\frac{x}{y}=\frac{I_{11}\cos\theta-I_2\sin\theta}{I_{11}\sin\theta+I_2\cos\theta}$$

or

$$\tan(\alpha-\gamma)=\frac{1-\frac{I_2}{I_{11}}\tan\theta}{\tan\theta+\frac{I_2}{I_{11}}}$$

From above

$$\frac{I_2}{I_{11}}=\frac{I_{2max}}{I_{11max}}\tan\theta$$

and from equation 3,

$$\frac{I_2}{I_{11}}=\frac{{}_{22}E_1S}{E_{11}}$$

therefore

$$\tan\theta=\frac{I_{11max}}{I_{2max}}\left(\frac{{}_{22}E_1S}{E_{11}}\right)$$

Since $\frac{E_{11}}{{}_{22}E_1}=\frac{N_{AW}}{N_1}=\tan\gamma$, it follows that

$$\tan\theta=\frac{I_{11max}}{I_{2max}}\left(\frac{S}{\tan\gamma}\right)$$

$$\tan(\alpha-\gamma)=\frac{1-\left(\frac{1}{\tan\gamma}\right)^2\left(\frac{I_{11max}}{I_{2max}}\right)S^2}{\left(\frac{1}{\tan\gamma}\right)\left(\frac{I_{11max}}{I_{2max}}+1\right)S}$$

Appendix C. List of Symbols

E_{11}—Voltage generated in adjusting winding between brushes supplying one phase of stator

E_2—Voltage induced in one phase of stator

${}_{22}E_1$—Stator voltage at standstill

ϕ—Total flux produced by primary windings

α—Angle between V_1 and I_{1L}

γ—Angle $\tan^{-1}\frac{N_{AW}}{N_1}$

$(\alpha-\gamma)$—Phase angle between total secondary phase current and voltage induced in stator

I_{1L}—Load component of primary current

I_1—Total primary phase current

I_{11}—Current flowing in stator and adjusting winding resulting from the voltage E_{11}

I_2—Current flowing in stator and adjusting winding resulting from the voltage E_2

I_{11max}—Maximum value of I_{11} and thus diameter of I_{11} circle

I_{2max}—Maximum value of I_2 and thus diameter of I_2 circle

N_1—Effective number of stator turns per phase

N_{AW}—Effective number of adjusting-winding turns per phase

R_{AW}—Resistance of adjusting winding per phase

R_1—Resistance of stator per phase

S—Per cent slip

θ—Phase angle between I_{11} and E_{11}, or I_2 and E_2

V_1—Voltage impressed upon one phase of primary

${}_{22}X_{AW}$—Adjusting-winding reactance at standstill

${}_{22}X_1$—Stator reactance at standstill

Reference

1. Theory of the Brush-Shifting A-C Motor—I, II. A. G. Conrad, F. Zweig, and J. G. Clarke. AIEE Transactions, volume 60, 1941, August section, pages 829–36.

Theory of the Brush-Shifting A-C Motor—IV

Speed Control With Power-Factor Correction

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J. G. CLARKE, ASSOCIATE AIEE

Synopsis: The preceding papers of this series presented an analysis of the brush-shifting a-c motor. Parts I and II dealt with the case when the voltage introduced into the stator coils from the commutator was collinear with the voltage induced in the stator coils by slip. Part III dealt with the case when the voltage introduced into the stator coils from the commutator was in quadrature with the induced voltage.

This paper extends the earlier analysis to include all the possible phase positions of the voltage introduced into the stator coils from the commutator. Under these conditions power factor and speed are controlled simultaneously. Methods for constructing the circle diagram for these conditions are given, and the characteristics of the motor predicted from the circle diagram are compared with the characteristics obtained by laboratory tests.

IT has been demonstrated[1] that the locus of the extremity of the current vector of the brush-shifting motor is a circle when the brushes are set for speed adjustment, that is, when the voltage, E_{11}, collected from the commutator is collinear with the induced voltage, E_2, in the stator. Further analysis[2] has shown that when the brushes are set to make E_{11} perpendicular to E_2 for the purpose of power-factor correction, that the locus of the extremity of the current vector is also a circle. An analysis of these circles has provided[1,2] a means of explaining the operation of the motor for these special brush settings and of predicting all of its characteristics from no-load measurements.

The developments described above have been made from an analysis of:

(*a*). The secondary currents I_{11} and I_2 produced by the voltages E_{11} and E_2 respectively.

(*b*). The magnetomotive forces produced by these currents flowing in the stator and the adjusting winding.

(*c*). The resultant magnetomotive forces produced in the primary winding as a result of the secondary magnetomotive forces.

(*d*). The primary currents associated with the required primary magnetomotive forces.

This paper, employing the same methods of analysis, extends the theory of the brush-shifting motor and explains its operation when the brushes are shifted to control speed at the same time that the motor is used to correct the power factor of its supply. Specifically, it deals with the operation of the motor when the brushes are set to make E_{11} out of phase with the standstill value of E_2 by any angle β. An understanding of the developments presented here presupposes a knowledge of the material presented in the preceding papers of this series.[1-3]

Figure 1a shows a representative vector diagram of the secondary currents I_{11} and I_2, and their loci when they are produced by the voltages E_{11} and E_2 which are no longer collinear. Appendix A demonstrates that the sum of I_{11} and I_2 for this condition is a vector the locus of which is defined by another circle. This circle, representing the locus of the sum of I_2 and I_{11}, is shown in Figure 1a. For the condition shown, the machine will run above synchronous speed at no load, and the power factor will be leading. The current vectors will follow the circle loci shown when the speed is varied from synchronous speed through higher speeds to infinite speed—infinite negative slip. Since the diameter of the I_{11} circle coincides with E_{11}, swinging E_{11} to various phase positions moves the I_{11} circle along with it. For values of β ranging from 0 to 180 degrees, a current is reflected into the primary which has a leading component over the operating range of the motor. The no-load speed of the machine is above synchronous speed if β is between 0 and 90 degrees, as in Figure 1, and below synchronous speed if β is between 90 and 180 degrees.

When the brushes are set to make E_{11} in the same direction as $_nE_2$, ($\beta=0$), the center lines of corresponding stator and adjusting winding coils are collinear, and their magnetomotive forces aid. With this reference position of E_{11}, β is also the angle by which the magnetomotive force of the adjusting winding lags the magnetomotive force of the stator coils. This is the angle in electrical degrees through which it is necessary to rotate the brushes about the commutator in order to shift E_{11} by β degrees (see Figure 2). Only the phase position of E_{11} is changed if the brushes are all rotated about the commutator by the same angle, keeping their relative spacing unchanged. Positive values of β are obtained by moving the brushes in the direction of rotation from the position where $\beta=0$. Values of magnetomotive force and of E_{11} identical to those at any given setting of the brushes can be obtained by rotating all brushes 360 electrical degrees around the commutator, or by interchanging the positions of all brush pairs, and moving them all 180 electrical degrees around the commutator.

Determination of the Primary Currents

The primary current resulting from the secondary currents shown in Figure 1a can be obtained from a consideration of the various magnetomotive forces involved. If the resultant flux crossing the air gap is to remain unchanged (so that the generated voltage will remain approximately equal and opposite to the applied voltage), the magnetomotive forces produced by the secondary currents flowing in the stator and the adjusting winding coils must be cancelled by component magnetomotive forces produced by component currents flowing in the primary coils.

While the polyphase current I_2+I_{11}, which flows in the stator coils also flows in the adjusting winding coils, the magnetomotive forces produced by these two sets of coils in series are not, in general, in the same time phase with respect to the primary. This is because the adjusting winding coils are mechanically displaced from the stator coils by β electrical degrees, as shown in Figure 2. If the brushes have been shifted to retard E_{11} by β degrees (which advances the primary current), the magnetomotive force of the adjusting winding lags the magnetomotive force of the stator by β degrees, so that the primary current cancelling the magnetomotive force of the adjusting winding lags the primary current which cancels the magnetomotive force of the stator by β degrees.

Figure 1b shows a vector diagram of the components of the primary current necessary to cancel the magnetomotive

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force produced by the secondary currents of Figure 1a flowing in the *stator*. Figure 2 shows that this component of primary current is obtained by a *mirror reflection* of the secondary current while the motor is running above synchronous speed, and by a *180-degree reflection* of the secondary current when the machine is running below synchronous speed. Figure 1c shows a vector diagram of the components of primary currents which cancel the magnetomotive forces of the secondary currents flowing in the *adjusting winding*. Figure 1d shows the magnetizing component of the primary current. Figure 1e shows the sum of these component currents, or I_1, the total primary current. At a given load, the currents reflected from the adjusting winding and the stator winding are separated by the angle β. Their sum is separated from the component reflected from the stator by the angle

$$\gamma = \tan^{-1} \frac{N_{AW} \sin \beta}{N_2 + N_{AW} \cos \beta}$$

The currents reflected into the primary from the stator and the adjusting winding bear the ratio N_2 to N_{AW}.

By adding the reflected currents vectorially, the load component of the primary current is obtained. The ratio of transformation between the secondary and the primary can be obtained from the equation

$$N_1 I_{1L} = \sqrt{(N_2 + N_{AW} \cos \beta)^2 + (N_{AW} \sin \beta)^2}\,(I_2 + I_{11})$$

Obtaining the Circle Diagram

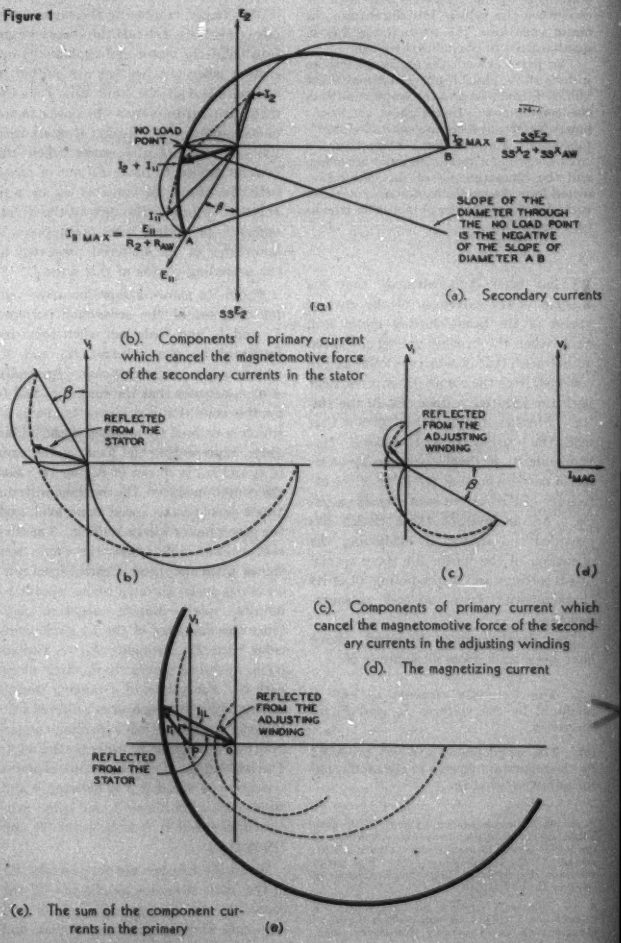
For specific cases, two general methods have been considered for obtaining the circle locus of the primary current without loading the machine. One method makes use of the fact that a circle is uniquely determined if two points and the slope of the diameter through one of the points is known. This method is commonly used to obtain the circle diagram for the two-element induction motor. It is also applicable for the brush-shifting a-c motor for any value of E_{11}. The two points commonly used are the extremities of the no-load and blocked-rotor current vectors. In the two-element induction motor, the diameter through the no-load point is 90 degrees behind the impressed voltage, so the circle can be constructed from these two currents. However, the presence of E_{11} in the brush-shifting a-c motor causes a shift of the diameter of the secondary current locus through the no-load point so that it is no longer perpendicular to E_2 (or the applied voltage). As is seen in Figure 1a, the tangent of the angle of slope of this diameter is

$$\frac{\dfrac{E_{11}}{R}\cos\beta}{\dfrac{{}_{ss}E_2}{X} + \dfrac{E_{11}}{R}\sin\beta} = \frac{\dfrac{E_{11}}{{}_{ss}E_2}\cos\beta}{\dfrac{R}{X} + \dfrac{E_{11}}{{}_{ss}E_2}\sin\beta}$$

where R and X are the total resistance and reactance at standstill referred to the secondary. The voltages and β in this equation may be determined by opening the brush leads and measuring E_{11}, ${}_{ss}E_2$, and $E_{11} + {}_{ss}E_2$. β is determined by forming a triangle of these three voltages. The quantities can also be determined directly if the brush positions and turns ratio are known. The remaining term, R/X, can be evaluated from the blocked rotor current. At standstill, the resultant secondary current, $I_{11} + I_2$, lags the resultant secondary voltage, $E_{11} + {}_{ss}E_2$, by an angle the tangent of which is X/R. This is the same angle that I_{1L} lags V_1 at standstill. Hence, X/R is the tangent of the angle between I_{1L} and V_1 at blocked rotor. The corresponding diameter of the primary current locus lags this diameter of the secondary current locus by the angle γ, which was defined earlier.

Erecting a perpendicular bisector to the chord joining the no-load and the blocked rotor current extremities gives another diameter, and the center of the

Figure 1


NO LOAD POINT
SLOPE OF THE DIAMETER THROUGH THE NO LOAD POINT IS THE NEGATIVE OF THE SLOPE OF DIAMETER A B
REFLECTED FROM THE STATOR
REFLECTED FROM THE ADJUSTING WINDING
REFLECTED FROM THE ADJUSTING WINDING
REFLECTED FROM THE STATOR

(a). Secondary currents

(b). Components of primary current which cancel the magnetomotive force of the secondary currents in the stator

(c). Components of primary current which cancel the magnetomotive force of the secondary currents in the adjusting winding

(d). The magnetizing current

(e). The sum of the component currents in the primary

primary-current circle locus lies at the intersection of these two diameters.

This method for determining the locus of the primary current, from the two points and the direction of the diameter through the no-load current extremity, involves the same approximation that is made in ordinary induction-motor theory—that this diameter of the circle passes through the no-load point. Actually, when the machine is running with no output torque, it is loaded with rotational losses. The circle should be constructed with the diameter drawn through the true no-load point, which can be found by supplying these losses mechanically. This refinement produces almost no change in the circle diagram.

The circle can also be located by obtaining three points, rather than by two points and a diameter. This method, which was discussed for specific cases in the earlier papers,[1,2] is valid for all brush positions, since the current locus is always a circle, and three points determine a circle. The necessary data are:

(*a*). The no-load input current and watts at normal voltage.

(*b*). The standstill input current and watts at reduced voltage.

(*c*). The no-load input current and watts at reduced voltage, with the machine running at some speed between the no-load speed and standstill.

This method eliminates the inaccuracies introduced by primary leakage reactance and rotational losses.

Characteristics From the Circle Diagram

When the locus of the extremity of the primary-current vector has been established by the methods discussed above, the characteristics of the motor can be predicted, using methods similar to those used in parts I, II, and III of this series.

In the ordinary induction-motor theory, it is assumed that the total copper loss of the motor is the loss produced by the no-load current plus the loss produced by the load component of current that is reflected from the secondary. The portion of the primary copper loss produced by the no-load current is grouped with the other no-load losses, and the sum of these is assumed to be constant. These assumptions involve two approximations, neither of which seriously affects the accuracy of the method for the two-element induction motor. First, it assumes that the current flowing in the primary is directly proportional to the current in the secondary, so that the division of copper loss between the primary and secondary is the same for all loads. Second, it assumes that the loss for two component currents flowing in a conductor simultaneously is equal to the sum of the losses produced when each component flows separately.

$$(I_{max}^2+I_{1L}^2)R_1=(I_{max}+I_{1L})^2R_1$$

This is true only when the component current vectors are in quadrature. Over the operating range of the ordinary induction motor, the magnetizing current is nearly at right angles to the reflected component, I_{1L}, so that the error due to this approximation is small. However, in the brush-shifting motor, the voltage E_{11} may be introduced into the secondary in such a phase position that the phase angle of the reflected current may vary widely with respect to the magnetizing current, introducing quite appreciable errors. The loss curves for the machine can be located without these approximations. Referring to Figure 3, for some general running condition when the input current is pf, the current flowing in the secondary is proportional to of, where po is the magnetizing current. po can be determined by running the machine at no load with the brushes set to make E_{11} zero. The primary copper loss is proportional to $(pf)^2$, and the secondary copper loss is proportional to $(of)^2$. When the rotor is blocked, the total input to the motor is used in supplying losses. Assuming that the sum of the iron, friction, and windage losses remains constant from no load to blocked rotor, the total copper loss can be determined for blocked rotor. From the resistances of the two windings, the division of this loss between the primary and the secondary can be determined. Thus, if the point m is located so that $rm\times V_1$ is the primary copper loss per phase for a primary current pb, and $mb\times V_1$ is the secondary copper loss per phase for a reflected current ob, then for a primary current pf, the primary copper loss per phase is $hk\times V_1$ where

$$hk=rm\frac{pf^2}{pb^2}$$

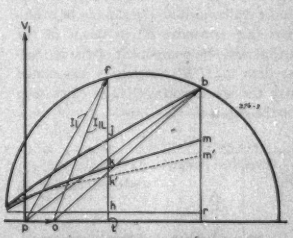


Figure 3. Locus of the primary current, and curves dividing the power component into the parts allocated to the output and the various losses

and the corresponding secondary loss is $kj\times V_1$ where

$$kj=mb\frac{of^2}{ob^2}$$

This method can be used to determine the copper losses at no load. By subtracting these copper losses from the no-load input, the friction, windage, and iron loss is determined.

Using these relations, curves can be constructed that divide the power component of the input current into the portions that are allocated to the output and the various losses. Thus, in Figure 3, for an input current pf:

Input = $tf\times V_1$ watts per phase
Output = $jf\times V_1$ watts per phase
Friction, windage, and iron loss = $th\times V_1$ watts per phase
Primary copper loss = $hk\times V_1$ watts per phase
Secondary copper loss = $kj\times V_1$ watts per phase

(a). Schematic diagram of the motor, showing the brushes set to retard E_{11} by β degrees. The magnetomotive force of the adjusting winding is β degrees behind that of the stator

(b). Effective currents, representing the magnetomotive forces of the stator, adjusting winding, and primary windings

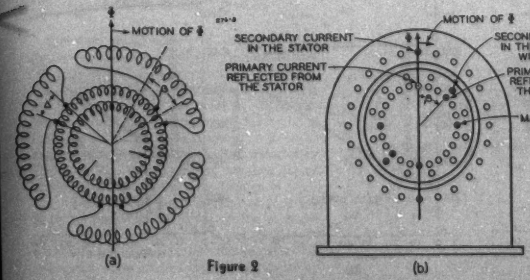


Figure 2

$$\text{Efficiency} = \frac{ij}{if}$$

$$\text{Power-factor} = \frac{if}{if}$$

When E_{11} has no quadrature component with respect to ${}_{ss}E_2$, ($E_{11} \sin \beta = 0$), the slip is equal to the secondary loss divided by the total power across the gap, or

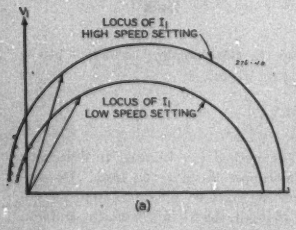
$$S = \frac{{}_{sec}(I^2R)}{\text{developed power} + {}_{sec}(I^2R)} \times 100 \text{ per cent of no-load speed}$$

where I is the total secondary current ($I_2 + I_{11}$). Under this condition, all of the I^2R loss in the secondary is supplied by the *speed* voltage, IZ, which varies directly with slip. Appendix B demonstrates that when E_{11} has any phase position β, the voltage supplying the secondary I^2R loss is a combination of a *speed* voltage $(IZ)_s$, which varies directly with slip, and a *transformer* voltage $(IZ)_t = E_{11} \sin \beta$, which is independent of slip. Under this condition, the slip can be evaluated (see appendix B) in terms of the output and the component of the secondary loss, ${}_{sec}(I^2R)_s$, which is associated with the speed voltage. The expression for the slip is

$$S = \frac{{}_{sec}(I^2R)_s}{\text{developed power} + {}_{sec}(I^2R)_s} \times 100 \text{ per cent of } N_o$$

Figure 4. Comparison of observed and predicted characteristics

Points are observed. Lines are predicted



(a)

This slip is expressed in per cent of N_o, the no-load speed at which the motor would operate if the brushes were shifted to eliminate the quadrature component ($E_{11} \sin \beta$) without altering the inphase component ($E_{11} \cos \beta$). Similarly, the torque can be shown to be proportional to the component of the total secondary power which is independent of the transformer voltage.

$$\text{Developed power} + {}_{sec}(I^2R)_s = \frac{2\pi N_o T_{dev}}{33{,}000} \times 746$$

or

$$T_{dev} = \frac{33{,}000}{2\pi N_o 746} (\text{developed power} + {}_{sec}(I^2R)_s)$$

The quantities ${}_{sec}(I^2R)_s$ and (developed power$+{}_{sec}(I^2R)_s$) may be evaluated by projecting the components of I_{1L} on V_1 as outlined in appendix B. Also, it can be shown that these quantities may be evaluated from the product of the projections of I_{1L} and V_1 on an axis lagging V_1 by γ degrees, and that ${}_{sec}(I^2R)_t$, the component of the loss associated with the transformer voltage, can be evaluated from the product of the projections of I_{1L} and V_1 on an axis perpendicular to this axis. Regardless of the method used to evaluate these quantities, it is convenient to draw the dotted line $m'k'$, and so forth, on the circle diagram of Figure 3, so that

${}_{sec}(I^2R)_t = k'k \times V_1$ watts per phase
${}_{sec}(I^2R)_s = k'j \times V_1$ watts per phase
Output$+{}_{sec}(I^2R)_s = k'f \times V_1$ watts per phase

From this, the slip and torque can be evaluated in a manner which is almost identical with that used for the ordinary induction motor circle diagram.

$$\text{Slip} = \frac{k'j}{k'f} \times 100 \text{ per cent of } N_o$$

$$\frac{2\pi N_o T}{33{,}000} \times 746 = k'f \times V_1 \text{ watts per phase}$$

This involves the same approximation that is made with the ordinary induction motor—that the effect of rotational losses on the slip is negligible.

Experimental Check on the Circle-Diagram Theory

To check the theory that has been presented here, tests were made on the General Electric *BTA* 550–1,650-rpm 4.17–12.5 horsepower 60-cycle brush-shifting motor that was used in the earlier tests.

The brushes were set for two tests so that β was approximately 45 degrees and 135 degrees. The power factor was improved with each of these settings, and the machine ran above synchronous speed when $\beta = 45$ degrees, and below synchronous speed when $\beta = 135$ degrees.

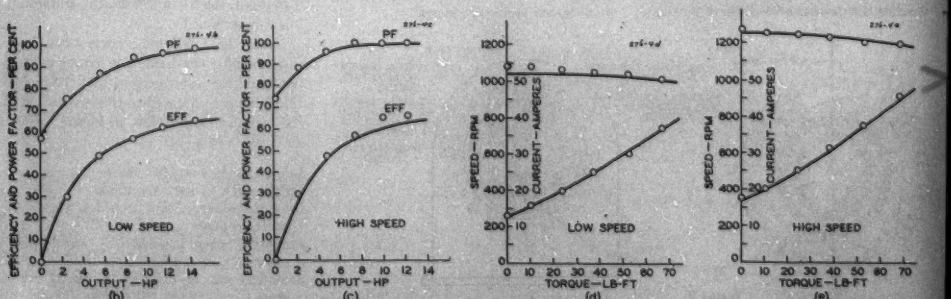
The magnitude and phase position of E_{11} were determined accurately by the voltage measurements described earlier, and from this, from the no-load measurements and from the blocked-rotor measurements, the circles shown in Figure 4a were constructed. It is seen that these predicted circles check the observed points quite closely. Curves of speed and current against torque, and power factor and efficiency against output were constructed from the predicted circle. Figures 4b, c, d, and e show these predicted characteristics compared with those actually observed.

Conclusions

1. Theory and experiments described here have shown that it is possible to adjust the brushes of the brush-shifting a-c motor to correct the power factor of the current supplying it, regardless of the speed to which it is adjusted.

2. The locus of the extremity of the primary current with such adjustments is a circle. The magnitude and location of this circle with respect to the primary-voltage vector can be determined from no-load measurements taken on the motor.

3. Power-factor correction is accomplished



by causing exciting current of the motor to flow in the secondary elements instead of the primary. This causes extra heating in the secondary and reduces the permissible load current that the secondary can carry. In the particular machine used in this investigation, values of the quadrature component of E_{11}, ($E_{11} \sin \beta$) in excess of 10 per cent of the standstill value of the induced secondary voltage E_2 cause excessive secondary currents.

4. While the range of $E_{11} \sin \beta$ (power-factor adjustment) is limited, $E_{11} \cos \beta$ (speed adjustment) is not limited except by the design of the motor. The voltage $E_{11} \cos \beta$ is opposed in normal operation by a speed voltage, E_2, which limits the flow of current produced by it. The quadrature component, $E_{11} \sin \beta$, causes a secondary current which is opposed only by the motor impedance and not by the speed voltage. Consequently, a small angle β can cause considerable change in power factor in a low impedance motor.

5. A method of determining the characteristics of the motor when used to perform the double function of speed adjustment and power-factor correction has been presented. This method employs the theory and use of the circle diagram. The accuracy of the predicted characteristics indicates that the theory and description of the operation of the motor as presented here are essentially correct.

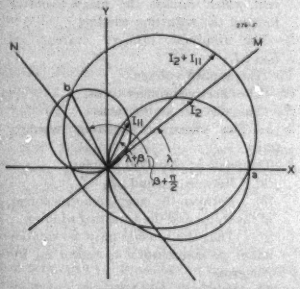


Figure 5. Diagram for appendix A

Appendix A. Proof of the Circle Locus of (I_2+I_{11})

The two small circles of Figure 5 with diameters a and b represent the loci of the currents I_2 and I_{11} respectively. Establish the rectangular co-ordinates, x and y, with the x axis along the diameter a. If angles are measured counterclockwise from the x axis, the angle between b and a is $\beta+\pi/2$. A current I_2 at angle λ from the x axis, when added to the corresponding current I_{11} at angle $\lambda+\beta$ from the x axis, results in (I_2+I_{11}). The locus of the extremity of (I_2+I_{11}) is to be expressed in terms of the x, y coordinates. To do this it is convenient to establish another set of rectangular co-ordinates m, n rotated counterclockwise by the angle λ from the x, y axis. It is seen that

$$m = I_2 + I_{11}\cos\beta = a\cos\lambda + b\sin\lambda\cos\beta$$
$$n = I_{11}\sin\beta = b\sin\lambda\sin\beta$$

By the Pythagorean theorem

$$(I_2+I_{11})^2 = (I_2+I_{11}\cos\beta)^2 + (I_{11}\sin\beta)^2$$
$$(I_2+I_{11})^2 = I_2^2 + I_{11}^2\cos^2\beta - ab\times\sin\beta\,(\sin^2\lambda+\cos^2\lambda) + ab\sin\beta$$

Since $I_2 = a\cos\lambda$ and $I_{11} = b\sin\lambda$

$$(I_2+I_{11})^2 = I_2^2 + I_{11}^2 + 2I_2I_{11}\cos\beta - a\sin\beta\times\sin\lambda I_{11} - b\sin\beta\cos\lambda I_2 + ab\sin\beta$$
$$= I_2^2 + I_{11}^2 + I_2I_{11}\cos\beta - I_2b\cos\lambda\times\sin\beta + I_2I_{11}\cos\beta - a\sin\beta\times\sin\lambda I_{11} + ab\sin\beta$$
$$= I_2^2 + I_{11}^2 + I_2b\sin\lambda\cos\beta - I_2b\times\cos\lambda\sin\beta + I_{11}a\cos\lambda\cos\beta - I_{11}a\sin\lambda\sin\beta + ab\sin\beta$$
$$= I_2^2 + I_{11}^2 + I_2b\sin(\lambda-\beta) + I_{11}a\times\cos(\lambda+\beta) + ab\sin\beta$$
$$= I_2[I_2 + b\sin(\lambda-\beta)] + I_{11}[I_{11} + a\times\cos(\lambda+\beta)] + ab\sin\beta$$
$$= I_2[a\cos\lambda + b\sin(\lambda-\beta)] + I_{11}\times\{b\sin[(\lambda-\beta)+\beta] + a\cos(\lambda+\beta)\} + ab\sin\beta$$
$$= I_2[a\cos\lambda + b\sin(\lambda-\beta)] + aI_{11}\times\cos\lambda\cos\beta - aI_{11}\sin\lambda\sin\beta + I_{11}b\sin(\lambda-\beta)\cos\beta + I_{11}b\times\cos(\lambda-\beta)\sin\beta + ab\sin\beta$$
$$(I_2+I_{11})^2 = [a\cos\lambda + b\sin(\lambda-\beta)](I_2+I_{11}\times\cos\beta) + I_{11}\sin\beta[b\cos(\lambda-\beta) - a\sin\lambda] + ab\sin\beta$$

Since $m = I_2 + I_{11}\cos\beta$ and $n = I_{11}\sin\beta$

$$(I_2+I_{11})^2 = [a\cos\lambda + b\sin(\lambda-\beta)]m + n\times[b\cos(\lambda-\beta) - a\sin\lambda] + ab\sin\beta$$
$$= m[\cos\lambda(a-b\sin\beta) + b\sin\lambda\times\cos\beta] + n[-\sin\lambda(a-b\sin\beta) + b\cos\lambda\cos\beta] + ab\sin\beta$$
$$(I_2+I_{11})^2 = (a-b\sin\beta)(m\cos\lambda - n\sin\lambda) + b\cos\beta(m\sin\lambda + n\cos\lambda) + ab\sin\beta$$

Since the co-ordinates x, y are expressed in the m, n co-ordinate system by the equations

$$x = m\cos\lambda - n\sin\lambda$$
$$y = m\sin\lambda + n\cos\lambda$$
$$(I_2+I_{11})^2 = (a-b\sin\beta)x + (b\cos\beta)y + ab\times\sin\beta$$

But

$$(I_2+I_{11})^2 = x^2+y^2$$

so

$$x^2 - x(a-b\sin\beta) + y^2 - yb\cos\beta = ab\sin\beta$$

Completing squares

$$\left[x-\left(\frac{a}{2}-\frac{b}{2}\sin\beta\right)\right]^2 + \left[y-\frac{b}{2}\cos\beta\right]^2 = ab\times\sin\beta + \frac{a^2}{4} - \frac{ab}{2}\sin\beta + \frac{(b\sin\beta)^2}{4} + \frac{(b\cos\beta)^2}{4}$$

$$\left[x-\left(\frac{a}{2}-\frac{b}{2}\sin\beta\right)\right]^2 + \left[y-\frac{b}{2}\cos\beta\right]^2 = \left[\frac{a}{2}+\frac{b}{2}\sin\beta\right]^2 + \left[\frac{b\cos\beta}{2}\right]^2$$

This is the equation of a circle in x, y co-ordinates with center at

$$x = \frac{a}{2} - \frac{b}{2}\sin\beta$$

$$y = \frac{b}{2}\cos\beta$$

and radius

$$r = \left[\left(\frac{a}{2}+\frac{b}{2}\sin\beta\right)^2 + \left(\frac{b\cos\beta}{2}\right)^2\right]^{1/2}$$

Appendix B. Determination of Slip and Torque

As is seen from Figure 1, I_{1L} is made up of two components, one of which, I_{1s}, cancels

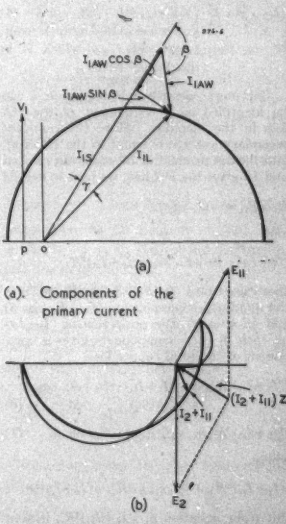


Figure 6. Diagrams for appendix B

the magnetomotive force of (I_2+I_{11}) flowing in the stator coils, and the other, I_{1AW}, cancels the magnetomotive force of (I_2+I_{11}) flowing in the adjusting winding. These component currents bear the ratio

$$\frac{I_{1s}}{I_{1AW}} = \frac{N_2}{N_{AW}} = \frac{{}_{22}E_2}{E_{11}}$$

and are added together at the angle β to form I_{1L} as shown in Figure 6a. Thus, if I_{1L}, β, and ${}_{22}E_2/E_{11}$ are known, all the component currents are determined.

By projecting the various current vectors in this diagram on the voltage vector, V_1, powers are obtained which can be used in evaluating the speed and torque.

If the vector notation $(I_{1L})\cdot(V_1)$ is used to mean the scalar product of V_1 and the projection of I_{1L} on V_1, and if the primary resistance is assumed to be transferred into the

secondary, the following relations may be written

$$(I_{12})\cdot(V_1)=(I_2+I_{11})\cdot(_{22}E_2+E_{11}) \quad (1)$$
$$=\text{net power transferred from the primary to the stator and the adjusting windings}$$

$$(I_{12})\cdot(V_1)=(I_2+I_{11})\cdot(_{22}E_2) \quad (2)$$
$$=\text{power transferred from the primary to the stator}$$

$$(I_{1AW})\cdot(V_1)=(I_2+I_{11})\cdot(E_{11}) \quad (3)$$
$$=\text{power transferred from the primary to the adjusting winding}$$

$$(I_{1AW}\cos\beta)\cdot(V_1)=(I_2+I_{11})\cdot(E_{11}\cos\beta) \quad (4)$$
$$=\text{power associated with the component of } I_{1AW} \text{ which is collinear with } I_{12}$$

$$(I_{1AW}\sin\beta)\cdot(V_1)=(I_2+I_{11})\cdot(E_{11}\sin\beta) \quad (5)$$
$$=\text{power associated with the component of } I_{1AW} \text{ which is in quadrature with } I_{12}$$

The power described by equation 5 can be identified as a component of the I^2R loss in the machine. Since the resultant secondary voltage is equal to the IZ drop; and the dot product of the resultant current and IZ gives the I^2R loss, we may write

$$E_2+E_{11}=-(I_2+I_{11})Z$$

and

$$(I_2+I_{11})\cdot(E_2+E_{11})=-(I_2+I_{11})^2R$$

(See Figure 6b.) If (E_2+E_{11}) is divided into the quadrature components $(E_2+E_{11}\cos\beta)$ and $(E_{11}\sin\beta)$, the projection of (I_2+I_{11}) on each of these components gives a component of the total copper loss.

$$[(I_2+I_{11})^2R]_s=-(I_2+I_{11})\cdot(E_2+E_{11}\cos\beta) \quad (6)$$

$$[(I_2+I_{11})^2R]_t=-(I_2+I_{11})\cdot(E_{11}\sin\beta) \quad (7)$$

where

$$[(I_2+I_{11})^2R]_s+[(I_2+I_{11})^2R]_t=(I_2+I_{11})^2R$$

But from equation 5, $[(I_2+I_{11})^2R]_t$ is seen to be the product of V_1 and the projection of $(I_{1AW}\sin\beta)$ on V_1, so that $[(I_2+I_{11})^2R]_t$ can be evaluated, and since $[(I_2+I_{11})^2R]$ is known, the remaining component $[(I_2+I_{11})^2R]_s$ can be evaluated.

Obtaining the Torque

The power which is transferred directly from the primary to the stator is, from equation 2

$$(I_{12})\cdot(V_1)=(I_2+I_{11})\cdot(_{22}E_2)$$

Since this power is transferred by a flux which reacts at synchronous speed with the primary

$$(I_{12})\cdot(V_1)=(I_2+I_{11})\cdot(_{22}E_2)=\frac{2\pi N_{sync}T_{dev}}{33{,}000}\times 746$$

which can be solved for torque. This assumes the more conventional form if it is expressed in terms of N_o rather than N_{sync}, where N_o is the no-load speed when $E_{11}\times\sin\beta$ is made zero, leaving $E_{11}\cos\beta$ unchanged.

$$(I_{12}+I_{1AW}\cos\beta)\cdot(V_1)=(I_2+I_{11})\cdot(_{22}E_2+E_{11}\cos\beta)=\frac{2\pi N_oT_{dev}}{33{,}000}\times 746 \quad (8)$$

This is true because

$$\frac{N_o}{N_{sync}}=\frac{_{22}E_2+E_{11}\cos\beta}{_{22}E_2}=\frac{I_{12}+I_{1AW}\cos\beta}{I_{12}}$$

From equations 1 and 5, it is seen that equation 8 must represent the developed power plus one component of the copper loss

$$\frac{2\pi N_oT_{dev}}{33{,}000}\times 746=P_{dev}+[(I_2+I_{11})^2R]_s$$

which can be solved for torque.

Obtaining the Speed

Since the slip from synchronous speed, in per cent of synchronous speed is $E_2/{}_{22}E_2$, the speed can be predicted from E_2. As is seen from Figure 6b

$$E_2=E_{11}\cos\beta+[(I_2+I_{11})Z]_s$$

where $[(I_2+I_{11})Z_s]$ is the component of the impedance drop which is in phase with E_2, so that

$$\frac{E_2}{{}_{22}E_2}=\frac{E_{11}\cos\beta}{{}_{22}E_2}+\frac{[(I_2+I_{11})Z]_s}{{}_{22}E_2}=S_1+S_2$$
$$=\text{slip in per cent of synchronous speed}$$

where S_1 is the slip caused by $E_{11}\cos\beta$ and S_2 is the slip caused by loading. The first term on the right hand side of this equation is constant for a given brush setting, and the second term varies with torque. This expression can be evaluated more simply if the slip is measured from N_o and expressed in per cent of N_o. This slip is

$$S=\frac{S_2N_{sync}}{N_o}=\frac{[(I_2+I_{11})Z]_s}{{}_{22}E_2+E_{11}\cos\beta}\text{ per cent } N_o$$

Here the slip is expressed in terms of the ratio of two voltages. Taking the dot product of these voltages with the secondary currents puts this expression for slip into the conventional form:

$$S=\frac{[(I_2+I_{11})Z]_s\cdot(I_2+I_{11})}{(_{22}E_2+E_{11}\cos\beta)\cdot(I_2+I_{11})}=\frac{[(I_2+I_{11})^2R]_s}{P_{dev}+[(I_2+I_{11})^2R]_s}\text{ per cent } N_o$$

Assumption Regarding Primary Resistance

In deriving the expressions for speed and torque, it was assumed that the primary resistance was replaced by an equivalent resistance in the secondary. Actually, the power consumed in the primary resistance does not cross the air gap. For this reason, the term $[(I_2+I_{11})^2R]_s$ in these expressions must be replaced by the term $_{sec}[(I_2+I_{11})^2R]_s$. This term, which is part of the copper loss in the secondary, was obtained in the manner commonly used for the ordinary induction motor. The division of the loss at blocked rotor was determined by resistance measurements, then it was assumed that the same division of losses occurred at all loads.

List of Symbols

E_{11}—The voltage inserted into the secondary element from the adjusting winding

E_2—The voltage induced in the secondary element by slip

I_{11}—The current flowing in the stator and adjusting winding, resulting from the voltage E_{11}

I_2—The current flowing in the stator and adjusting winding, resulting from the voltage E_2

I—The resultant secondary current I_2+I_{11}

$_{22}E_2$—The value of E_2 when the rotor is blocked

I_{mag}—The flux-producing component of the primary current

I_{1L}—The component of the primary current which cancels the magnetomotive forces of the stator and the adjusting windings

I_{12}—The component of the primary current which cancels the magnetomotive force of the stator winding

I_{1AW}—The component of the primary current which cancels the magnetomotive force of the adjusting winding

I_1—The resultant primary current, or $I_{mag}+I_{1L}$

V_1—The applied voltage

N_1—The effective primary turns

N_2—The effective stator turns

N_{AW}—The effective adjusting winding turns

β—The angle in electrical degrees
- (*a*). Between E_{11} and $_{22}E_2$
- (*b*). Between the magnetomotive forces of the stator and the adjusting winding
- (*c*). That the brushes must be rotated about the commutator to retard E_{11} by β degrees

γ—The angle in electrical degrees
- (*a*). Between I_{12} and I_{1L}
- (*b*). Between the magnetomotive force of the stator and the resultant magnetomotive force of the stator and the adjusting winding (*c*). Between $_{22}E_2$ and $(_{22}E_2+E_{11})$

R—The resistance of the primary, secondary, and adjusting winding, reflected to the secondary

X—The standstill reactance of the primary, secondary, and adjusting winding, reflected to the secondary

Z—The secondary and adjusting winding impedance

T_{dev}—The developed torque

P_{dev}—The developed power

$(IZ)_s$—The component of the total secondary and adjusting winding IZ voltage which is in phase with E_2

$(IZ)_t$—The component of the total secondary and adjusting winding IZ voltage which is in quadrature with E_2: $(IZ)_t=-E_{11}\sin\beta$

$_{sec}(I^2R)_s$—The component of the secondary I^2R loss which is given by $I\cdot(IZ)_s$

$_{sec}(I^2R)_t$—The component of the secondary I^2R loss which is given by $I\cdot(IZ)_t$

N_o—The no-load speed at which the motor

Reactance and Skin Effect of Concentric Tubular Conductors

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THE concentric arrangement of tubular conductors to carry heavy alternating currents gives compactness, low reactance drop, and reduced loss from skin effect or crowding of the current to the surface of the conductors. This arrangement is being used to a considerable extent.[1,2] In this paper formulas and curves are given to enable the reactance and the skin-effect resistance ratio of such conductors to be determined for three-phase and single-phase circuits.

Reactive Drop

In practical cases the reactance of concentric tubular conductors is very little affected by the variable current density which causes skin effect. When uniform current density is assumed, the "geometric mean distance" method of Clerk Maxwell may be used. Using values given in paragraph 692 of his "Electricity and Magnetism," for geometric mean distances of a tubular section from itself and from other sections, (references 1, 3, and equations 28 and 30 of reference 11) formulas for the reactance drop in each tube of a concentric, three-phase circuit are obtained.

The general formula for reactive drop in conductor 1 of a group of long, parallel conductors is (see reference 11, equation 55, page 39)

$$-j\omega 2\times 10^{-9}[I_1 \operatorname{logn} D_{s1}+I_2 \operatorname{logn} D_{12}+ I_3 \operatorname{logn} D_{13}+\ldots] \text{ volts per centimeter} \quad (1)$$

where

ω = $2\pi\times$frequency,
logn denotes natural logarithm,
D_{s1} = self geometric mean distance of conductor 1,
D_{12} = geometric mean distance of the cross section of conductor 1 to that of conductor 2, and so forth.

The currents are in amperes. A conductor may have any shape of cross section.

The logarithm of the geometric mean distance between two cross sections is the average of the logarithms of all possible distances between points on one section and points on the other. The logarithm of the self geometric mean distance of the section of a conductor is the average of the logarithms of all possible distances between any two points of the section.

Formula 1 is subject to the condition that

$$I_1+I_2+I_3+I_4+\ldots=0$$

which is a relation usually obtained in any steady-state problem where a system consists of long, parallel conductors, and all the conductors are taken into account. In other words there is as much return current as there is going current in such a system. A system of this kind may be made up of any number of phases and any number of conductors in parallel.

Let the inside and outside diameters of the tubes, from the smallest to the largest, be d_1, d_2, d_3, d_4, d_5, and d_6. Let there be no neutral current.

The reactive drop in the inner tube, which carries I_a amperes, is, in volts per centimeter,

$$\frac{j\omega 2I_a}{10^9}\left[\frac{d_1^4}{(d_2^2-d_1^2)^2}\operatorname{logn}\frac{d_2}{d_1}-\frac{3d_1^2-d_2^2}{4(d_2^2-d_1^2)}\right]+ \frac{j\omega 2I_b}{10^9}\left[\frac{1}{2}+\frac{d_2^2}{d_3^2-d_2^2}\operatorname{logn}\frac{d_2}{d_3}-\frac{d_3^2}{d_3^2-d_2^2}\operatorname{logn}\frac{d_4}{d_3}\right]+ \frac{j\omega 2I_c}{10^9}\left[\frac{1}{2}+\frac{d_5^2}{d_5^2-d_4^2}\operatorname{logn}\frac{d_5}{d_4}-\frac{d_4^2}{d_5^2-d_4^2}\operatorname{logn}\frac{d_6}{d_5}\right] \quad (2)$$

The reactive drop in the intermediate tube, which carries I_b amperes, is

$$\frac{j\omega 2I_a}{10^9}\left[\frac{1}{2}-\frac{d_2^2}{d_2^2-d_1^2}\operatorname{logn}\frac{d_2}{d_3}\right]+ \frac{j\omega 2I_b}{10^9}\left[\frac{d_2^4}{(d_2^2-d_3^2)^2}\operatorname{logn}\frac{d_4}{d_3}-\frac{3d_3^2-d_2^2}{4(d_2^2-d_3^2)}\right]+ \frac{j\omega 2I_c}{10^9}\left[\frac{1}{2}+\frac{d_5^2}{d_5^2-d_4^2}\operatorname{logn}\frac{d_5}{d_4}-\frac{d_4^2}{d_5^2-d_4^2}\right]\times \operatorname{logn}\frac{d_5}{d_4} \text{ volts per centimeter} \quad (3)$$

Reactive drop in the outer tube, which carries I_c amperes, is

$$\frac{j\omega 2(I_a+I_b)}{10^9}\left[\frac{1}{2}-\frac{d_5^2}{d_5^2-d_4^2}\operatorname{logn}\frac{d_5}{d_6}\right]+ \frac{j\omega 2I_c}{10^9}\left[\frac{d_5^4}{(d_5^2-d_4^2)^2}\operatorname{logn}\frac{d_5}{d_6}-\frac{3d_5^2-d_4^2}{4(d_5^2-d_4^2)}\right] \text{ volts per centimeter} \quad (4)$$

The phase currents I_a, I_b, and I_c may be unbalanced. Therefore, by putting one of the currents equal to zero, the single-phase case is included.

For deriving the first expression, note that

$$I_a \operatorname{logn} d_2=-I_b \operatorname{logn} d_3-I_c \operatorname{logn} d_3$$

since there is no neutral current, and similarly for d_4 in the second expression and for d_6 in the third.

If the thickness of the above tubes is considered negligible, regarding the effect on the reactive drop, and if, as before, there is no neutral current, the reactive drop in the inner tube is

$$-\frac{j\omega 2}{10^9}\left[I_b \operatorname{logn}\frac{d_4}{d_2}+I_c \operatorname{logn}\frac{d_6}{d_2}\right] \text{ volts per centimeter} \quad (5)$$

Reactive drop in the intermediate tube is

$$-\frac{j\omega 2}{10^9}I_c \operatorname{logn}\frac{d_6}{d_4} \text{ volts per centimeter} \quad (6)$$

Reactive drop in the outer tube = 0. (7)

It does not matter in what units the diameters are given, in equations 2 to 6, so long as they are all in the same units, since only ratios of diameters occur.

For convenience in computation, it may be noted that there are

$$2.540\times 12{,}000=3.05\times 10^4 \text{ centimeters in 1,000 feet} \quad (8)$$

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would operate if the brushes were shifted to eliminate E_{11} sin β, leaving E_{11} cos β unchanged

References

1. THEORY OF THE BRUSH-SHIFTING A-C MOTOR—I, A. G. Conrad, F. Zweig, J. G. Clarke. AIEE TRANSACTIONS, volume 60, 1941, August section, pages 829–33.

2. THEORY OF THE BRUSH-SHIFTING A-C MOTOR—II, A. G. Conrad, F. Zweig, J. G. Clarke. AIEE TRANSACTIONS, volume 60, 1941, August section, pages 834–6.

3. THEORY OF THE BRUSH-SHIFTING A-C MOTOR—III, A. G. Conrad, F. Zweig, J. G. Clarke. AIEE TRANSACTIONS, volume 61, 1942, July section, pages 502–06.

Also,

$$\log n = 2.3026 \log_{10} n \qquad (9)$$

The resistance drop in each tube is added vectorially to the reactance drop to give the impedance drop in that tube.

Example 1. Find the reactance drop in each tube of the following concentric, three-phase circuit. The inside and outside diameters of the inner tube are 1.2 and 3.0 inches; those of the intermediate tube are 4.0 and 4.5 inches, and those of the outer tube are 5.6 and 6.0 inches. The current of the inner tube is one ampere; that of the intermediate tube is

$$\cos 120° + j \sin 120° = -0.5 + j0.866$$

and that of the outer tube is

$$\cos 240° + j \sin 240° = -0.5 - j0.866$$

The reactive drop in the inner tube is

$$\frac{j\omega 2}{10^9}\,[0.188 - 0.349(-0.5 + j0.866) - 0.660 \times (-0.5 - j0.866)]$$

$$= \frac{j\omega 2}{10^9}(0.692 + j0.270) \text{ volts per centimeter}$$

to compare with $j\omega 2(0.55 + j\,0.25)/10^9$ by the approximate formula 5.

The reactive drop in the intermediate tube is

$$\frac{j\omega 2}{10^9}\,(0.164 + j0.253)$$

to compare with $j\omega 2(0.14 + j0.25)/10^9$ by the approximate formula 6.

The reactive drop in the outer tube is

$$\frac{j\omega 2}{10^9}\,(0.028 + j0.048)$$

to compare with 0 by the approximate formula 7.

For the resistance drop in each tube see example 2.

Skin Effect at Low Frequency

Let there be a tubular conductor of inner radius q and outer radius r, as in Figure 1. Let there be uniform current density a_o abamperes per square centimeter in the tube and let there be a current I_p in a wire at the center of the tube.

Following the procedure of reference 5, beginning at equation 1 of that paper

$$\text{Flux density at } dx = (\text{current inside } dx)\frac{2}{q+x}$$

$$= 2\pi a_o q\left(\frac{2x}{q} - \frac{x^2}{q^2} + \frac{x^3}{q^3} - \frac{x^4}{q^4} + \dots\right) + \frac{2I_p}{q}\left(1 + \frac{x}{q}\right)^{-1} \qquad (10)$$

Integrate from x to t and multiply by $j\omega$ where $\omega = 2\pi \times$ frequency.

Put

$$\frac{4\pi\omega}{\rho} = m^2 \qquad (11)$$

where ρ = resistivity of the metal in abohms per centimeter cube. Reactive drop at dx caused by flux inside radius r due to a_o and I_p

$$= \frac{jm^2t^2}{2!}a_o\rho\left[1 - \frac{1}{3}\frac{t}{q} + \frac{1}{4}\frac{t^2}{q^2} - \dots - \frac{x^2}{t^2} + \frac{1}{3}\frac{x^3}{t^2q} - \frac{1}{4}\frac{x^4}{t^2q^2} + \dots\right] + \frac{j\omega 2I_p\rho}{q}\left[1 - \frac{1}{2}\frac{t}{q} + \frac{1}{3}\frac{t^2}{q^2} - \dots - \frac{x}{t} + \frac{1}{2}\frac{x^2}{tq} - \frac{1}{3}\frac{x^3}{tq^2} + \dots\right] \qquad (12)$$

Let a current density $a_1 + a_1'$ flow, such that its resistance drop will be equal and opposite to the terms in x of equation 12, in order to keep the voltage drop from all causes uniform over the section, as it is in actual fact.

$$a_1 = \frac{jm^2t^2}{2!}a_o\left(\frac{x^2}{t^2} - \frac{1}{3}\frac{x^3}{t^2q} + \frac{1}{4}\frac{x^4}{t^2q^2} - \dots\right) \qquad (13)$$

$$a_1' = \frac{j\omega 2I_p}{q\rho}\left(x - \frac{1}{2}\frac{x^2}{q} + \frac{1}{3}\frac{x^3}{q^2} - \frac{1}{4}\frac{x^4}{q^3} + \dots\right) \qquad (14)$$

These currents will in turn produce flux in the metal and from the terms in x of the resulting voltage drops there are obtained values of current densities a_2 and a_2' and so on. The resulting values are

$$a_2 = \frac{(jm^2t^2)^2}{4!}a_o\left[\frac{x^4}{t^4} - \frac{2}{5}\frac{x^5}{t^4q} + \frac{3}{10}\frac{x^6}{t^4q^2} \cdots\right]$$

$$a_3 = \frac{(jm^2t^2)^3}{6!}a_o\left[\frac{x^6}{t^6} - \frac{3}{7}\frac{x^7}{t^6q} + \frac{9}{28}\frac{x^8}{t^6q^2} \cdots\right]$$

$$a_4 = \frac{(jm^2t^2)^4}{8!}a_o\left[\frac{x^8}{t^8} - \frac{4}{9}\frac{x^9}{t^8q} + \frac{1}{3}\frac{x^{10}}{t^8q^2} \cdots\right]$$

$$a_3' = \frac{jm^2t^2}{3!}\frac{j\omega 2I_p}{\rho}\left[\frac{x^3}{t^2q} - \frac{1}{2}\frac{x^4}{t^2q^2} + \frac{7}{20}\frac{x^5}{t^2q^3} - \frac{11}{40}\frac{x^6}{t^2q^4} \cdots\right]$$

$$a_5' = \frac{(jm^2t^2)}{5!}\frac{j\omega 2I_p}{\rho}\left[\frac{x^5}{t^4q} - \frac{1}{2}\frac{x^6}{t^4q^2} + \frac{5}{14}\frac{x^7}{t^4q^3} - \frac{2}{7}\frac{x^8}{t^4q^4} \cdots\right]$$

$$a_4' = \frac{(jm^2t^2)^2}{7!}\frac{j\omega 2I_p}{\rho}\left[\frac{x^7}{t^6q} - \frac{1}{2}\frac{x^8}{t^6q^2} + \frac{13}{36}\frac{x^9}{t^6q^3} - \frac{7}{24}\frac{x^{10}}{t^6q^4} \cdots\right]$$

Let the total current in the tube be I. By integrating the complete expression for current density over the cross section of the tube

$$I = \pi a_o(2qt + t^2)\left[1 + c_1\frac{jm^2t^2}{3!} + c_2\frac{(jm^2t^2)^2}{5!} + \dots\right] + I_p\left[d_1\frac{jm^2t^2}{2!} + d_2\frac{(jm^2t^2)^2}{4!} + d_3\frac{(jm^2t^2)^3}{6!} + \dots\right] \qquad (15)$$

where

$$c_1 = 1 - \frac{1}{20}\frac{t^2}{q^2} + \frac{1}{20}\frac{t^3}{q^3} - \frac{11}{280}\frac{t^4}{q^4} + \dots$$

$$c_2 = 1 - \frac{1}{14}\frac{t^2}{q^2} + \frac{1}{14}\frac{t^3}{q^3} - \dots$$

$$c_3 = 1 - \frac{1}{12}\frac{t^2}{q^2} + \dots$$

$$c_4 = 1 - \frac{1}{11}\frac{t^2}{q^2} + \dots$$

as in reference 5, and where

$$d_1 = 1 + \frac{1}{3}\frac{t}{q} - \frac{1}{12}\frac{t^2}{q^2} + \frac{1}{30}\frac{t^3}{q^3} - \dots$$

$$d_2 = 1 + \frac{2}{5}\frac{t}{q} - \frac{1}{10}\frac{t^2}{q^2} + \frac{3}{70}\frac{t^3}{q^3} - \dots$$

$$d_3 = 1 + \frac{3}{7}\frac{t}{q} - \frac{3}{28}\frac{t^2}{q^2} + \frac{1}{21}\frac{t^3}{q^3} - \dots$$

$$d_4 = 1 + \frac{4}{9}\frac{t}{q} - \frac{1}{9}\frac{t^2}{q^3} + \dots$$

This gives the value of a_o in terms of I and I_p.

If the tube were not present, the center conductor carrying I_p would supply its resistance loss including its own eddy-current loss. Then, as stated by Waldo V. Lyon[6] at the top of page 1377, AIEE TRANSACTIONS, 1921, in his paper on eddy-current losses in armature conductors, if the outer tube and its current I be introduced, it does not change the eddy-current loss in the inner conductor, and the total additional power supplied by the circuits to the two conductors is equal to the resistance loss of the tube. There is a transfer of power from the inner conductor to the tube. These amounts of power can be computed.

In the work so far, magnetic flux outside the tube has not been considered as it would not change any of the current densities. It will be included now in computing the transfer of power, and, as would be expected, it will be shown that it has no effect on the expression for eddy-current loss.

The voltage drop in all elements of the tube is the same as that at its outer surface and is

$$j\omega 2(I + I_p)\log_n\frac{s}{r} + \rho i_{(r)} \qquad (16)$$

where $i_{(s)}$ is the current density at the outer surface and where s is a certain large distance to which flux is counted. Since the expression in s will finally cancel out, the result is the same no matter how large a value of s is chosen.

Let conj I be the conjugate of I, that is, the same complex quantity except with j changed to $-j$. Multiply equation 16 by conj I and take the real part, to obtain the power delivered to the tube from its own circuit, per centimeter of the tube. This is

$$\text{Re conj } I\, j\omega 2(I+I_p)\log\frac{s}{r}+$$
$$\text{Re conj } I\, a_o\rho\left[1+b_1\frac{jm^2t^2}{2!}+b_2\frac{(jm^2t^2)^2}{4!}+\ldots\right]+Re\text{ conj } I\, I_p\frac{j\omega 4t}{2q+t}\left[e_1+e_2\frac{jm^2t^2}{3!}+e_3\frac{(jm^2t^2)^2}{5!}+\ldots\right] \quad (17)$$

where Re denotes "real part of." Note that in this paper conj applies only to the single letter which follows it, but Re applies to the complete expression which follows.

$$b_1=1-\frac{1}{3}\frac{t}{q}+\frac{1}{4}\frac{t^2}{q^2}-\ldots$$
$$=\frac{1}{2}+\frac{q}{t}-\frac{q^2}{t^2}\log_n\left(1+\frac{t}{q}\right)$$
$$b_2=1-\frac{2}{5}\frac{t}{q}+\frac{3}{10}\frac{t^2}{q^2}-\frac{17}{70}\frac{t^3}{q^3}\cdots$$
$$b_3=1-\frac{3}{7}\frac{t}{q}+\frac{9}{28}\frac{t^2}{q^2}-\frac{11}{42}\frac{t^3}{q^3}\cdots$$
$$b_4=1-\frac{4}{9}\frac{t}{q}+\frac{1}{3}\frac{t^2}{q^2}\cdots$$
$$b_5=1-\frac{5}{11}\frac{t}{q}+\frac{15}{44}\frac{t^2}{q^2}\cdots$$

as in reference 5.

$$e_1=1+\frac{1}{12}\frac{t^2}{q^2}-\frac{1}{12}\frac{t^3}{q^3}+\frac{3}{40}\frac{t^4}{q^4}-\frac{1}{15}\frac{t^5}{q^5}\cdots$$
$$=\left(\frac{1}{2}+\frac{q}{t}\right)\log_n\left(1+\frac{t}{q}\right)$$
$$e_2=1+\frac{1}{10}\frac{t^2}{q^2}-\frac{1}{10}\frac{t^3}{q^3}+\frac{51}{560}\frac{t^4}{q^4}\cdots$$

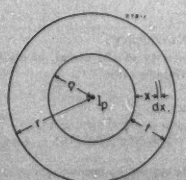


Figure 1. Tubular conductor and central wire

$$e_3=1+\frac{3}{28}\frac{t^2}{q^2}-\frac{3}{28}\frac{t^3}{q^3}\cdots$$
$$e_4=1+\frac{1}{9}\frac{t^2}{q^2}-\frac{1}{9}\frac{t^3}{q^3}\cdots$$

The total flux caused by the current in the tube, as far as radius s, is

$$2I\log\frac{s}{r}+4\pi a_o\rho\left[\frac{b_1}{2!}+b_2\frac{jm^2t^2}{4!}+b_3\frac{(jm^2t^2)^2}{6!}+\ldots\right]+\frac{4I_p\rho}{2q+t}\left[e_2\frac{jm^2t^2}{3!}+e_3\frac{(jm^2t^2)^2}{5!}+\ldots\right] \quad (18)$$

Multiply by $j\omega$ to obtain the voltage induced in the central conductor. Then multiply by conj I_p and take the real part to obtain the additional power supplied by the circuit of the central conductor. This power is transferred to the tube and helps supply the resistance loss in the tube. By adding equation 17, the total resistance loss in the tube is found to be

$$\text{Re conj } I(I)\,j\omega 2\log\frac{s}{r}+\text{Re conj } I\,a_o\rho\times\left[1+b_1\frac{jm^2t^2}{2!}+b_2\frac{(jm^2t^2)^2}{4!}+\ldots\right]+$$
$$\text{Re conj } I\,I_p\frac{j\omega 4t}{2q+t}\times\left[e_1+e_2\frac{jm^2t^2}{3!}+e_3\frac{(jm^2t^2)^2}{5!}+\ldots\right]+$$
$$\text{Re conj } I_p(I)j\omega 2\log\frac{s}{r}+$$
$$\text{Re conj } I_p a_o\rho\left[b_1\frac{jm^2t^2}{2!}+b_2\frac{(jm^2t^2)^2}{4!}+\ldots\right]+$$
$$\text{Re conj } I_p\,I_p\frac{j\omega 4t}{2q+t}\left[e_1\frac{jm^2t^2}{3!}+e_2\frac{(jm^2t^2)^2}{5!}+\ldots\right] \quad (19)$$

Now conj $I\,I$ is a real quantity, $|I|^2$, since

$$(a-jb)(a+jb)=a^2+b^2+j0$$

conj $I\,I_p+I$ conj I_p is also a real quantity, since

$$(a-jb)(c+jd)+(a+jb)(c-jd)=2ac+2bd+j0$$

It is the sum of a complex quantity and its conjugate. Therefore, the terms in $\log n\ s/r$ have no real part and disappear.

The resistance loss in the tube, then, is

$$\text{Re conj } Ia_o\rho+\text{Re}(\text{conj } I+\text{conj } I_p)a_o\rho\times\left[b_1\frac{jm^2t^2}{2!}+b_2\frac{(jm^2t^2)^2}{4!}+\ldots\right]+$$
$$\text{Re}\frac{j\omega 4t}{2q+t}\left[\text{conj } I\,I_p e_1+I_p\ (\text{conj } I+\text{conj } I_p)\left\{e_1\frac{jm^2t^2}{3!}+e_2\frac{(jm^2t^2)^2}{5!}+\ldots\right\}\right] \quad (20)$$

Note that the real parts of the entire expressions are taken.

Equations 15 and 20 can be applied to the three tubes in succession of a three-phase concentric circuit, thus obtaining the skin-effect resistance ratio of each tube, that is, the ratio of the resistance loss in the tube compared to the loss with direct current of the same amperage.

The power lost in a tube with direct current of amperage I is

$$\frac{|I|^2\rho}{\pi(2qt+t^2)} \quad (21)$$

The skin-effect resistance ratio of the inner tube is the same as that of an isolated tube, since the surrounding tubes do not affect its current density. In this case, $I_p=0$. The formulas and curves were published in reference 5.

Dividing equation 20 by equation 21 and substituting the value of a_o given by equation 15,

$$\frac{R_{ac}}{R_{dc}}=\text{Re}\frac{1+b_1\frac{jm^2t^2}{2!}+b_2\frac{(jm^2t^2)^2}{4!}+\ldots}{1+c_1\frac{jm^2t^2}{3!}+c_2\frac{jm^2t^2}{5!}+\ldots} \quad (22)$$

for the inner tube.

For the intermediate tube

$$\frac{R_{ac}}{R_{dc}}=\text{Re}\frac{LM}{Q}+\text{Re}S \quad (23)$$

where

$$L=1+\left(1+\frac{\text{conj } I_p}{\text{conj } I}\right)\left\{b_1\frac{jm^2t^2}{2!}+b_2\frac{(jm^2t^2)^2}{4!}+\ldots\right\} \quad (24)$$

$$M=1-\frac{I_p}{I}\left\{d_1\frac{jm^2t^2}{2!}+d_2\frac{(jm^2t^2)^2}{4!}+\ldots\right\} \quad (25)$$

$$Q=1+c_1\frac{jm^2t^2}{3!}+c_2\frac{(jm^2t^2)^2}{5!}+\ldots \quad (26)$$

(Same as equation 16, reference 5, or denominator of 22)

$$S=\frac{I_p}{I}e_1\frac{jm^2t^2}{1!}+\left(\frac{I_p}{I}+\left|\frac{I_p}{I}\right|^2\right)\times\left\{e_2\frac{(jm^2t^2)^2}{3!}+e_3\frac{(jm^2t^2)^2}{5!}+\ldots\right\} \quad (27)$$

In balanced three-phase circuits, for the two opposite phase rotations

$$\frac{I_p}{I}=-\frac{1}{2}+j\frac{\sqrt{3}}{2}\ \text{ or }\ -\frac{1}{2}-j\frac{\sqrt{3}}{2} \quad (28)$$
$$1+\frac{\text{conj } I_p}{\text{conj } I}=\frac{1}{2}-j\frac{\sqrt{3}}{2}\ \text{ or }\ \frac{1}{2}+j\frac{\sqrt{3}}{2}$$
$$\frac{I_p}{I}+\left|\frac{I_p}{I}\right|^2=\frac{1}{2}+j\frac{\sqrt{3}}{2}\ \text{ or }\ \frac{1}{2}-j\frac{\sqrt{3}}{2}$$

The two opposite phase rotations produce slightly different amounts of eddy-cur-

rent loss, that is, different values of R_{ac}, depending on whether the greater current density is produced in the inner or the outer surface of the intermediate tube. See Figure 3.

For the outer tube

$I_p = -I$, and

$$\frac{R_{ac}}{R_{dc}} = \mathrm{Re}\frac{1+d_1\frac{jm^2t^2}{2!}+d_2\frac{(jm^2t^2)^2}{4!}+\ldots}{1+c_1\frac{jm^2t^2}{3!}+c_2\frac{(jm^2t^2)^2}{5!}+\ldots} \quad (29)$$

Equations 22, 23, and 29 give the skin-effect resistance ratio of the three tubes of a three-phase concentric tubular circuit. They are applicable up to about $mt=4$ and $t/d=0.2(t/q=1/4)$, as in reference 5.

The values of the ratios are plotted in Figure 2 on a base of thickness of copper tube, for standard frequency and temperature. This can save the work of computing by the formulas, in cases where the curves apply. For a frequency f such as 25 or 50 cycles, multiply the tube thickness by $\sqrt{f/60}$ before reading from the curves.

In order to show that there is a larger skin-effect ratio for the intermediate tube than for the others, the current density in the three phases is plotted in Figure 3, as computed by equation 13 and following formulas. The case chosen is that of three flat straps, which is the same as that of three concentric tubes with extremely large radii.

The skin-effect resistance ratio of the outer tube of a single-phase concentric circuit is the same as the ratio for the outer tube of a three-phase concentric circuit as given by Figure 2 or equation 29, since the total current inside the tube in either case is $-I$. The resistance ratio of the inner tube of a single-phase concentric circuit, and also the ratio of an isolated tube, are the same as that of the inner tube of a three-phase circuit, as given by Figure 2 or equation 22. See also references 5 and 7.

Example 2. Find the effective resistance at 60 cycles and 75 degrees centigrade of the three copper tubes described in example 1.

The inner tube, whose inside and outside diameters are 1.2 and 3.0 inches, has a resistance to direct current of 5.47×10^{-8} ohm per centimeter. From Figure 2, taking $t=0.9$ inch and $t/d=0.3$, the skin-effect resistance ratio is 1.92. Then R_{ac} for 60 cycles is

$5.47\times10^{-8}\times1.92=1.050\times10^{-7}$ ohm per centimeter

This is to be used for resistance drop and copper loss in the inner tube.

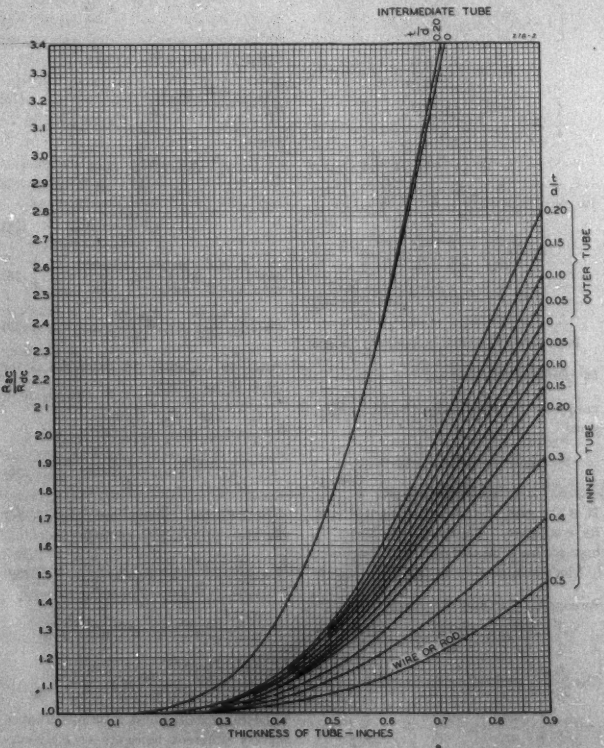
For the intermediate tube, with inside and outside diameters 4.0 and 4.5 inches, and thickness 0.25 inch, the resistance to direct current is 9.74×10^{-8}. From Figure 2, $R_{ac}/R_{dc}=1.059$ and therefore $R_{ac}=1.030\times10^{-7}$ ohm per centimeter.

For the outer tube, the inside and outside diameters are 5.6 and 6.0 inches. The resistance ratio, from Figure 2, is 1.008 and

$R_{ac}=8.92\times10^{-8}\times1.008=8.99\times10^{-8}$ ohm per centimeter

Figure 2. Skin-effect ratios for solid copper tubes, 75 degrees centigrade, 60 cycles, three phase

Thickness = t and outside diameter = d, of the tube being considered



Bessel-Function Formulas for Single-Phase Concentric Circuits and Isolated Tubes

The well-known solution for skin effect in an isolated tube in terms of Bessel functions is as follows.[3,7]

$$\frac{R_{ac}}{R_{dc}} = \mathrm{Re}\frac{\alpha t(q+r)}{2r}\times \frac{I_0(\alpha r)K_0'(\alpha q)-K_0(\alpha r)I_0'(\alpha q)}{I_0'(\alpha r)K_0'(\alpha q)-K_0'(\alpha r)I_0'(\alpha q)} \quad (30)$$

where I_0 and K_0 are modified Bessel functions of the first and second kinds, of order zero, Re denotes real part of

r = outside radius
q = inside radius
t = thickness of tube $= r-q$
$a^2=\dfrac{j4\pi\omega}{\rho}=jm^2$
$\alpha=\dfrac{m}{\sqrt{2}}$
$j=\sqrt{-1}$
$\omega=2\pi\times$frequency
ρ = resistivity of the metal, in abohms per centimeter cube

Note that

$$I_0(\alpha r)=\mathrm{ber}\ mr+j\ \mathrm{bei}\ mr \quad (31)$$

$$K_0(\alpha r)=\mathrm{ker}\ mr+j\ \mathrm{kei}\ mr \quad (32)$$

$$I_0'(\alpha r)=e^{-i\pi/4}(\mathrm{ber}'\ mr+j\ \mathrm{bei}'\ mr) \quad (33)$$

$$K_o'(\alpha r) = e^{-j\pi/4}(\text{ker}' mr + j\,\text{kei}' mr) \qquad (34)$$

Equation 30 is applicable to the inner tube of a concentric circuit, and to a non-concentric circuit in which the conductors are separated by more than a few diameters and proximity effect is considered negligibly small.

For the outer tube of a concentric circuit, where all the return conductors are within the outer tube[3,4]

$$\frac{R_{ac}}{R_{dc}} = \text{Re}\,\frac{-\alpha t(q+r)}{2q} \times \frac{I_o(\alpha q)K_o'(\alpha r) - K_o(\alpha q)I_o'(\alpha r)}{I_o'(\alpha q)K_o'(\alpha r) - K_o'(\alpha q)I_o'(\alpha r)} \qquad (35)$$

This is the same as formula 30 for an isolated tube, except interchange q and r and multiply by -1. Both formulas 30 and 35 may be derived by following the general method used in references 7 and 4

Formulas 30 and 35 may be used for direct computation of numerical problems, using tabulated values from references 7, 8, 9, or 10.

For very small or very large values of the argument, or for tubes whose thickness is small compared to their radius, series formulas, as given in this paper, may be shorter to use.

High-Frequency Formulas

For frequencies higher than 60 cycles, formulas derived from the asymptotic expansions of Bessel functions are often convenient. Except that they do not give any effect of radiation, and that they apply only to the dominant mode of transmission in a coaxial line, they are applicable to very high frequency since they are series with powers of the frequency in the denominators of the terms. As is usual with power series, their applicability depends on the rapidity with which the terms of the series become smaller and smaller.

Formulas of this type for the inner and outer conductors are given here. They are applicable to single-phase, concentric circuits and the formula for the inner conductor is applicable also to all the tubular conductors of circuits which are not concentric and in which the conductors are separated by more than a few diameters. With high frequency, such circuits are more likely to occur than three-phase concentric circuits.

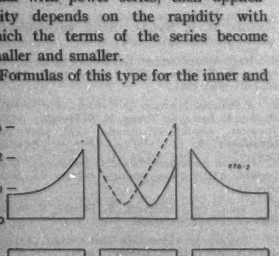


Figure 3. Current density in three-phase strap conductors, closely adjacent

Current density for same amperage of direct current = 1. $mt = \sqrt{6}$. The dotted line is for opposite phase rotation

To express equation 30 as a power series using asymptotic expansions (see reference 10, items 810.6, 810.7, 816.1, and 816.2) we have

$$-\frac{I_o'(\alpha q)}{K_o'(\alpha q)} = \frac{I_1(\alpha q)}{K_1(\alpha q)}$$

$$= \frac{e^{2\alpha q}}{\pi} \frac{1 - \frac{3}{1!8\alpha q} + \frac{3\times5}{2!(8\alpha q)^2} - \frac{3^2\times5\times7}{3!(8\alpha q)^3} \cdots}{1 + \frac{3}{1!8\alpha q} - \frac{3\times5}{2!(8\alpha q)^2} + \frac{3^2\times5\times7}{3!(8\alpha q)^3} \cdots}$$

$$= \frac{e^{2\alpha q}}{\pi}\left[1 - \frac{6}{8\alpha q} + \frac{18}{(8\alpha q)^2} - \frac{204}{(8\alpha q)^3} \cdots\right]$$

$$\frac{Z_{ac}}{R_{dc}} = \frac{\alpha t(q+r)}{2r} \frac{N}{D}$$

where

$$N = e^{\alpha r}\left\{1 + \frac{1}{8\alpha r} + \frac{9}{2(8\alpha r)^2} + \frac{75}{2(8\alpha r)^3} \cdots\right\} + e^{2\alpha q - \alpha r}\left\{1 - \frac{1}{8\alpha r} + \frac{9}{2(8\alpha r)^2} - \frac{75}{2(8\alpha r)^3} \cdots\right\} \times \left\{1 - \frac{6}{8\alpha q} + \frac{18}{(8\alpha q)^2} - \frac{204}{(8\alpha q)^3} \cdots\right\}$$

and

$$D = e^{\alpha r}\left\{1 - \frac{3}{8\alpha r} - \frac{15}{2(8\alpha r)^2} - \frac{105}{2(8\alpha r)^3} \cdots\right\} - e^{2\alpha q - \alpha r}\left\{1 + \frac{3}{8\alpha r} - \frac{15}{2(8\alpha r)^2} + \frac{105}{2(8\alpha r)^3} \cdots\right\} \times \left\{1 - \frac{6}{8\alpha q} + \frac{18}{(8\alpha q)^2} - \frac{204}{(8\alpha q)^3} \cdots\right\}$$

Then

$$\frac{Z_{ac}}{R_{dc}} = \frac{\alpha t(q+r)}{2r}\left[1 + \frac{4}{8\alpha r} + \frac{24}{(8\alpha r)^2} + \frac{192}{(8\alpha r)^3} \cdots + 2e^{-2\alpha t}\left\{1 + \frac{6}{8\alpha r} + \frac{42}{8\alpha r)^2} + \frac{348}{(8\alpha r)^3} \cdots\right\} \times \left\{1 - \frac{6}{8\alpha q} + \frac{18}{(8\alpha q)^2} - \frac{204}{(8\alpha q)^3} \cdots\right\} + \text{terms in } e^{-4\alpha t} \cdots\right] = \frac{t(q+r)}{r^2} \times \left[\frac{\alpha r}{2} + \frac{1}{4} + \frac{3}{16\alpha r} + \frac{3}{16\alpha^2 r^2} \cdots + e^{-2\alpha t} \times \left\{\alpha r + \frac{3}{4} + \frac{21}{32\alpha r} \cdots\right\}\left\{1 - \frac{3}{4\alpha q} + \frac{9}{32\alpha^2 q^2} \cdots\right\} + \text{terms in } e^{-4\alpha t} \cdots\right]$$

omitting the final terms of the last two brackets. Now

$$\alpha = me^{j\pi/4} = m\left(\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}\right)$$

$$\frac{1}{\alpha} = \frac{1}{m}e^{-j\pi/4} = \frac{1}{m}\left(\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}\right)$$

$$\frac{1}{\alpha^2} = \frac{1}{m^2}e^{-j\pi/2} = \frac{1}{m^2}(0 - j)$$

$$e^{-2\alpha t} = e^{-mt\sqrt{2}}(\cos mt\sqrt{2} - j \sin mt\sqrt{2})$$

(See reference 10, item 408.05) Taking the real part, the resistance ratio for an isolated tube is

$$\frac{R_{ac}}{R_{dc}} = \frac{t(q+r)}{r^2}\left[\frac{mr}{2\sqrt{2}} + \frac{1}{4} + \frac{3}{16mr\sqrt{2}} + \frac{0}{r^2} \cdots + e^{-mt\sqrt{2}}(\cos mt\sqrt{2})\left\{\frac{mr}{\sqrt{2}} - \frac{3}{4}\frac{t}{q} + \frac{3}{32mr\sqrt{2}}\left(7 - 6\frac{r}{q} + 3\frac{r^2}{q^2}\right) \cdots\right\} + e^{-mt\sqrt{2}}(\sin mt\sqrt{2})\left\{\frac{mr}{\sqrt{2}} - \frac{3}{32mr\sqrt{2}} \times \left(7 - 6\frac{r}{q} + 3\frac{r^2}{q^2}\right) \cdots\right\} + \text{terms in } e^{-2mt\sqrt{2}} \cdots\right] \qquad (36)$$

The first line is seen to be the series that is applicable to solid wire. Formula 36 was given a number of years ago in his Master of Science thesis at Massachusetts Institute of Technology by J. M. Roberts, now professor of electrical engineering at the University of Louisville, Louisville, Kentucky.

The expansion of formula 35 for large values of m is not obtained by interchanging q and r in formula 36, for $e^{-mt\sqrt{2}}$ would become $e^{mt\sqrt{2}}$. The expansion is made by taking $K_o(\alpha q)/K_o'(\alpha q)$ as the initial part. The result is:

High-frequency formula for resistance ratio of outer tube:

$$\frac{R_{ac}}{R_{dc}} = \frac{t(q+r)}{q^2}\left[\frac{mq}{2\sqrt{2}} - \frac{1}{4} + \frac{3}{16mq\sqrt{2}} + \frac{0}{q^2} \cdots + e^{-mt\sqrt{2}}(\cos mt\sqrt{2})\left\{\frac{mq}{\sqrt{2}} - \frac{3}{4}\frac{t}{r} + \frac{3}{32mq\sqrt{2}}\left(7 - 6\frac{q}{r} + 3\frac{q^2}{r^2}\right) \cdots\right\} + e^{-mt\sqrt{2}}(\sin mt\sqrt{2})\left\{\frac{mq}{\sqrt{2}} - \frac{3}{32mq\sqrt{2}} \times \left(7 - 6\frac{q}{r} + 3\frac{q^2}{r^2}\right) \cdots\right\} + \text{terms in } e^{-2mt\sqrt{2}} \cdots\right] \qquad (37)$$

The Penetration Formula

The "penetration formula" is a well-known and useful method for computing the a-c resistance of conductors at moder-

ately high frequencies. However, special precautions should be taken in using it for tubes, and these will now be described.

A convenient statement of the penetration formula, arranged so as to give a close approximation to the Bessel function solution at high frequencies, is that the alternating current is taken to penetrate, at uniform current density, to a depth δ_1 and the a-c resistance is taken to be equal to the d-c resistance of a tube consisting of the surface layer of metal of thickness δ_1. The formula for the thickness is

$$\delta_1 = \sqrt{2}/m \qquad \text{centimeters} \quad (38)$$

where

$$m = \sqrt{(4\pi\omega/\rho)}$$

and where ρ is in abohms per centimeter cube (see equation 11).

For an isolated round wire or tube of outside radius r, the effective resistance, then, is that of a tube of cross section

$$\pi\{r^2-(r-\delta_1)^2\} = 2\pi r\delta_1\left(1-\frac{\delta_1}{2r}\right) = \frac{2\pi\sqrt{2}}{m}\left(1-\frac{1}{mr\sqrt{2}}\right) \quad (39)$$

from equation 38.

The resistance ratio by the penetration formula is the ratio of the two cross sections, which is

$$\frac{\pi(r^2-q^2)m}{2\pi\sqrt{2}}\left(1-\frac{1}{mr\sqrt{2}}\right)^{-1} = \frac{t(q+r)}{r^2}\times\left(\frac{mr}{2\sqrt{2}}+\frac{1}{4}+\frac{1}{4mr\sqrt{2}}+\dots\right) \quad (40)$$

by the binomial expansion of $(1-x)^{-1}$.

The first two terms of the series in equation 40 are the same as in formula 36. These two terms give the equation of the straight line which is the asymptote of the curve of R_{ac}/R_{dc} plotted on mt, as in Figure 3, reference 5.

In order for equation 40 to agree with the corresponding portion of formula 36 within what might be called slide-rule accuracy, or about 0.5 per cent, it is necessary for $1/8m^2r^2$ to be less than 0.005. That is

$$\frac{\delta_1}{r} < \frac{1}{4} \quad (41)$$

This is often expressed by stating that the penetration depth δ_1 should be a small fraction of the radius of curvature, and under such a condition it can apply to conductors that are not round.

In the case of round tubes, another requirement is found from equation 36, namely, that the penetration depth δ_1 should be a small part of the thickness t. Equation 40 plainly does not take care of the terms in $\epsilon^{-mt\sqrt{2}}$ of formula 36, and so, if the penetration formula is to be a good approximation, these terms should be proportionately small. This leads to the condition that

$$\frac{\delta_1}{t} < 0.3 \text{ approximately} \quad (42)$$

In most cases, if equation 42 is complied with, then the requirement of equation 41 also is met.

The penetration formula can be applied to the inner surface of the outer tube of a concentric circuit.

Example 3. Find the skin-effect resistance ratio for an outer tube in which $mt = 3.2$, $mq = 4.8$, and $mr = 8$.

$$\frac{q+r}{2q} = \frac{4}{3},\quad \alpha t = mte^{j\pi/4}$$

$$I_0(\alpha q) = \text{ber } mq + j\,\text{bei } mq$$
$$= \text{ber } 4.8 + j\,\text{bei } 4.8$$
$$= -5.45 + j0.884$$

$$K_0'(\alpha r) = \epsilon^{-j\pi/4}(\text{ker}'\ 8.0 + j\,\text{kei}'\ 8.0)$$
$$= \epsilon^{-j\pi/4}(-0.000880 - j0.001336)$$

By equation 35,

$$\frac{R_{ac}}{R_{dc}} = \text{Re}\left\{-3.2(0+j)\times\frac{4}{3}\right\}\frac{-0.447+j0.376}{0.629}$$
$$= 2.55 \text{ by equation 35}$$

From equation 37

$$\frac{t(q+r)}{q^2} = 1.777$$

First line of equation 37
$$= 1.697 - 0.25 + 0.0276$$
$$= 1.475$$

$mt\sqrt{2} = 4.525 \qquad \epsilon^{-4.525} = 0.01083$

$\cos 4.525 = -0.1858$

Second line of equation 37
$$= 0.01083 \times (-0.1858)(3.39 - 0.30 + 0.062\dots)$$
$$= -0.00634$$

Third line of equation 37
$$= 0.01083 \times (-0.983)(3.39 - 0.062)$$
$$= -0.0354$$

$$\frac{R_{ac}}{R_{dc}} = 1.777(1.475 - 0.0063 - 0.0354)$$
$$= 2.55$$

Thickness of tube in inches, for copper at 75 degrees centigrade and 60 cycles

$$m^2 = \frac{4\pi\omega}{\rho} = \frac{4\pi\times 120\pi}{1{,}724}\times\frac{234+20}{234+75}$$
$$= 2.26$$

$$m = 1.504$$

$$\text{thickness} = \frac{3.2}{1.504}\times\frac{1}{2.54} = 0.838 \text{ inch}$$

$$t/d = \frac{3.2}{2\times 8} = 0.2$$

From Figure 2

$$R_{ac}/R_{dc} = 2.54$$

By the penetration formula, the section of the equivalent tube of thickness δ_1 is

$$\pi\{(q+\delta_1)^2 - q^2\} = 2\pi q\delta_1\left(1+\frac{\delta_1}{2q}\right) = \frac{2\pi q\sqrt{2}}{m}\left(1+\frac{1}{mq\sqrt{2}}\right)$$
by equation 38

$$\frac{R_{ac}}{R_{dc}} = \frac{\pi t(q+r)m}{2\pi q\sqrt{2}\left(1+\frac{1}{mq\sqrt{2}}\right)} = \frac{3.2\times 12.8}{2(6.78+1)} = 2.63$$

which is three per cent too large.

$$\delta_1 = \frac{\sqrt{2}}{1.504} = 0.94 \text{ centimeter or } 0.37 \text{ inch}$$

$$\frac{\delta_1}{t} = \frac{0.37}{0.838} = 0.44$$

which is somewhat too large for the employment of the penetration formula.

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Standardized Load-Center Unit Substations for Low-Voltage A-C Systems

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THE tremendous expansion of production facilities necessitated by American defense and war efforts has given the manufacturer of electrical equipment a serious challenge. Entire large defense projects, such as manufacturing plants, navy yards, drydocks, air depots, and office buildings, have been built in incredibly short times. Any one of these projects will not be complete without an electrical distribution system. One of the many tasks before the electrical manufacturer is to produce the necessary apparatus for the electrical distribution systems, and have it available by the time the project is ready to receive it.

In most of the recent projects power has been distributed to ultimate loads by means of the load-center power distribution systems. This type, although only recently applied to low-voltage systems, has been used successfully for years on high-voltage systems in the central station field. The essentials of load-center distribution for low-voltage a-c systems are

1. A large load area is divided into small load areas, each ranging from 600 to 1,000 kva at 480 volts for example.

2. Power is distributed at medium voltage (2.4 to 13.2 kv) to substations, located near the electrical load center in each of the small areas where the voltage is transformed to utilization voltage to service the area loads.

It has been found that the load-center distribution system when properly applied is superior to other systems from a performance standpoint, and less costly. One of the most important contributions of the electrical manufacturer to the field of low-voltage a-c systems in recent years has been the development and standardization of the load-center unit substation to service the small load areas described above. To the purchaser of electrical apparatus, the development and standardization of the load-center unit substation means that a complete, co-ordinated, pre-engineered step-down substation for a low-voltage a-c system may be ordered in the same manner as a standard motor or standard motor-control equipment.

It is the purpose of this paper to present

1. A definition of a load-center unit substation.

2. The general requirements which have been met by the standardized line with which the writers are most familiar.

3. A description of units with illustrations.

4. Tables for the ready selection of load-center unit substations.

For clarity the term "load-center unit substation" is defined here as follows:

A completely metal-enclosed integrated substation equipment incorporating

1. The required high-voltage switching, control, and incoming circuit termination facilities.

2. Transformer section or sections to transform a-c power from the medium-voltage range (2,400 to 15,000 volts) to the low-voltage range of 600 volts and below.

3. The required low-voltage switching, control, and outgoing feeder circuit termination facilities.

An installation view of a load-center unit substation is shown on Figure 1.

General Considerations

The load-center distribution system is generally thought of in connection with servicing a fairly large area with power. Thus the ultimate areas to be served usually consist of large buildings, mines, yards, docks, piers, camps, and so forth.

Safety considerations usually limit the highest voltage at which power may be carried within the load area to 13.2 kv. It is usually uneconomical to carry power to load-center locations at less than 2,400 volts because of the large cable required to carry the higher currents. Thus, for a given application any one of the medium voltages may be selected for this service, depending on local conditions and the requirements to be met. Consequently, from the electrical manufacturer's point of view, equipment must be available for the medium voltages, such as 2,400, 4,160, 4,800, 7,200, 12,000, and 13,200 volts.

When the circuit voltage of the available power supply is above 13.2 kv, it is generally advisable to step this down to a voltage in the medium-voltage range for distribution to the load area. This can be conveniently accomplished by means of a multicircuit unit substation, such as is shown on Figure 2. Where many such load areas are to be served, and service reliability is at a premium, two sources of supply may be brought in, or the master substations can be networked to form a primary network. A mobile substation can be used to serve as a spare, similar to the one shown on Figure 3.

From the standpoint of the load-center distribution, there are four types of basic

Figure 1. Indoor installation view of load-center unit substation, Pyranol-filled, rated three-phase, 60 cycles, 100 kva, 2,400 to 208/120 volts

Unit has two sets of primary cutouts for alternate supply and two low-voltage air circuit breakers for feeder protection. Located under crane rails, and supplies power to fluorescent lamps

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Figure 2. Outdoor unit substation rated three-phase, 60 cycles, 4,500 kva self-cooled, 6,000 kva forced air-cooled, 13,800 to 2,400 volts

Unit has four outgoing feeder circuit breakers and is located next to building it serves

Figure 3. Side view of 1,000-kva mobile substation

circuit arrangements used.[1] These may be described as

1. The straight radial system.

2. The primary-selective system which comprises two primary lines brought into each load-center unit substation, usually with provision for connection to only one line at a time.

3. The radial-primary secondary-selective system, which involves bringing in only one source of primary power, while utilizing normally open secondary tie circuits to other substations to obtain power for emergency operation.

Table I. General Requirements of Load-Center Unit Substations

Requirement Item	Rating or Description of Substation
Frequency	Practically all 60 cycles
Phases	Three
Kva ratings	100, 200, 300, 450, 500, 600, 750, 1,000, 1,200, 1,500, 2,000
Primary voltage	2,400, 4,160, 4,800, 7,200, 12,000, 13,200
Secondary voltage	600, 480, 240, 208/120
Transformer coolant	Pyranol, oil, air
Incoming primary feeders	One or two (switches or circuit breakers)
Outgoing secondary feeders	Any number (usually less than ten air circuit breakers)
Enclosures	Indoor: general purpose outdoor: weatherproof
System type	
1. Straight radial	One incoming primary circuit to substation, radial secondary feeders
2. Primary selective	Preferred and emergency incoming primary circuits to substation, radial secondary feeders
3. Secondary selective	One incoming primary circuit to substation, radial secondary feeders with secondary emergency tie circuits to other substations
4. Secondary network	One incoming primary circuit to substation, secondary-network protector, radial secondary feeders, secondary tie circuits

4. The low-voltage network scheme.

Any one or several of these basic systems may be used in a given application, depending upon the requirements to be met.

The low-voltage ratings of load-center unit substations are fixed by the American Standards Association standard three-phase transformer voltages which are 600, 480, 240, and 208/120 *Y* volts. It has been found that the ASA standard kilovolt-ampere ratings, from 100 through 2,000 kva inclusive, cover nearly 100 per cent of the application requirements for this type of equipment.

The requirements as to location are such that it is essential to have available units for both indoor and outdoor service. These two types allow the distribution engineer to locate the substation in electrical load-center locations, often in space that would otherwise be worthless. An installation view of an outdoor unit is shown on Figure 4.

Thus, the general requirements to be met by such equipment may be tabulated as in Table I.

Description of Equipment

The transformer section of the load-center unit substation consists of a three-phase transformer with leads from the high- and low-voltage windings brought out of the tank through side-wall bushings to metal-enclosed bus connections known as throats. The throats are built integral with the transformer tanks, with the low-voltage throat located on one short-dimension side of the tank and the high-voltage throat located on the opposite side of the tank. The high-voltage throat is arranged so that any one of a number of high-voltage arrangements of switching equipment and cable-termination apparatus may be connected to it, while the low-voltage throat is arranged for connection to metal-enclosed low-voltage switchgear.

The high-voltage equipment may consist of metal-enclosed switchgear. Circuit breakers are available with interrupting ratings from 25,000 to 150,000 kva in 5-kv metal-clad equipments, and 250,000

Figure 4. Outdoor installation view of load-center unit substation, Pyranol-filled, rated three-phase, 60 cycles, 1,500 kva, 13,800 to 575 volts

Unit has primary liquid-filled disconnecting switch and ten low-voltage air circuit breakers for protection of feeders supplying office building. Transformer at right is spare

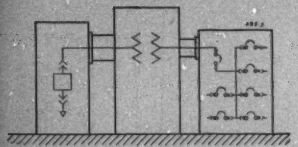

Figure 5. Load-center unit substation with one primary circuit breaker

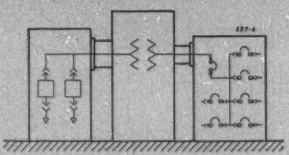

Figure 6. Load-center unit substation with two primary circuit breakers

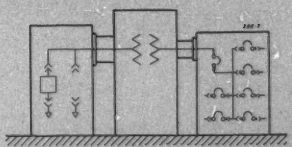

Figure 7. Load-center unit substation with two primary circuit-breaker positions and one circuit breaker

Load-Center Unit-Substation Application Table II. 120/208 Y Volts, Three-Phase

For Use in Connection With Load-Center Unit Substations

Available Primary 3-Phase Short-Circuit Kva	Transformer Kilovolt-Ampere Rating: 100	150	200	300	450	500	600	750	1,000	1,200	1,500
	Normal Current (Amperes): 278	417	556	834	1,250	1,388	1,665	2,080	2,780	3,330	4,164
I. For Transformer Main Low-Voltage Breaker (Selection Based on Adequate Interrupting and Current Rating)											
25,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
50,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
75,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
100,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
150,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
250,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
500,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	100-AL2
Unlimited	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2	
I. For Transformer Multiple Low-Voltage Breakers (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)											
25,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	100-AL2	100-AL2
250,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	100-AL2	100-AL2
500,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2	100-AL2
Unlimited	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2	
III. For Branch Circuit Breakers Co-ordinated With Transformer Main Low-Voltage Breaker (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)											
25,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	
IV. Total Low-Voltage Short-Circuit Currents—Amperes RMS (Impedances as Given in Table V, Total Connected Motor Kilovolt-Amperes Equals 50 Per Cent of Transformer Rating)											
25,000	8,580	12,300	13,300	18,800	26,100	28,300	32,300	35,800	43,500	48,600	55,700
50,000	8,970	13,200	14,200	20,700	29,600	32,400	37,800	42,300	53,300	61,000	71,600
75,000	9,110	13,400	14,600	21,300	31,000	34,100	40,100	45,200	57,800	64,900	79,800
100,000	9,170	13,500	14,800	21,700	31,800	35,000	41,300	46,800	60,400	70,500	84,800
150,000	9,240	13,700	14,900	22,100	32,600	36,000	42,700	48,500	63,300	74,400	90,600
250,000	9,280	13,900	15,000	22,400	33,300	36,800	43,900	50,000	65,900	77,900	95,700
500,000	9,350	14,000	15,100	22,600	33,800	37,500	44,800	51,300	67,900	81,000	100,000
Unlimited	9,380	14,100	15,200	22,900	34,400	38,100	45,900	52,500	70,200	84,100	105,000
V. Transformer Impedance Per Cent	4.0	4.0	5.0	5.0	5.0	5.0	5.0	5.5	5.5	5.5	5.5

1. For different voltage base, multiply values in Table IV by the ratio: Standard voltage/New voltage
2. Transformer contributes approximately 91 per cent of total short-circuit current for 50 per cent connected motors

VI. Magnetic Air Circuit Breakers Available

Type	Interrupting Rating (RMS Amperes)	Standard Continuous-Current Trip Ratings (Amperes)
15-AE1A	15,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225
25-AE1B	25,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600
50-AL-2	50,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600, 800, 1,000, 1,200, 1,600
75-AL-2	75,000	2,000, 2,500, 3,000
100-AL-2	100,000	4,000, 5,000, 6,000

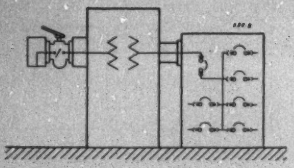

Figure 8. Load-center unit substation with primary flange-mounted liquid-filled cutouts

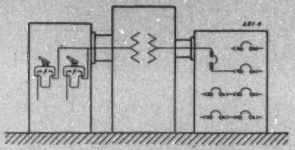

Figure 9. Load-center unit substation with two sets of primary liquid-filled cutouts in free standing enclosure

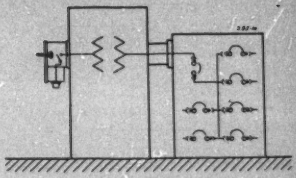

Figure 10. Load-center unit substation with primary liquid-filled flange-mounted switch

Load-Center Unit-Substation Application Table III. 240 Volts, Three-Phase

For Use In Connection With Load-Center Unit Substations Only

Available Primary 3-Phase Short-Circuit Kva	Transformer Kilovolt-Ampere Rating										
	100	150	200	300	450	500	600	750	1,000	1,200	1,500
	Normal Current (Amperes)										
	241	361	481	722	1,083	1,203	1,443	1,804	2,406	2,886	3,609
I. For Transformer Main Low-Voltage Breakers (Selection Based on Adequate Interrupting and Current Rating)											
25,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2
50,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2
75,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2
100,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2
150,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2
250,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2	100-AL2
500,000	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2	100-AL2
Unlimited	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2	100-AL2
II. For Transformer Multiple Low-Voltage Breakers (Selection Based on Adequate Interruping Rating Only. Check Current Ratings From Table V)											
25,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	75-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	100-AL2	100-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2	100-AL2	100-AL2
III. For Branch Circuit Breakers Co-ordinated With Transformer Main Low-Voltage Breaker (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)											
25,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2
IV. Total Low-Voltage Short-Circuit Current—RMS Amperes (Impedances As Given in Table V, Total Connected Motor Kilovolt-Amperes Equals 100 Per Cent of Transformer Rating)											
25,000	8,040	11,600	12,800	18,200	25,200	27,500	31,600	35,600	43,700	52,500	57,300
50,000	8,370	12,300	13,500	19,720	28,300	31,100	36,300	41,300	52,200	57,000	71,200
75,000	8,470	12,600	13,800	20,300	29,600	32,500	38,300	43,700	56,100	62,700	78,300
100,000	8,550	12,700	14,000	20,600	30,200	33,300	39,400	45,100	58,300	66,200	82,500
150,000	8,610	12,800	14,100	21,000	30,900	34,200	40,600	46,600	60,800	70,000	87,500
250,000	8,650	12,900	14,200	21,200	31,500	34,900	41,700	48,000	63,000	73,700	92,000
500,000	8,700	13,000	14,300	21,500	32,000	35,500	42,400	49,000	64,800	76,800	95,900
Unlimited	8,730	13,100	14,400	21,700	32,500	36,100	43,300	50,100	66,700	80,200	100,000

1. For different voltage base, multiply values in Table IV by the ratio: Standard voltage/New voltage

2. Transformer contributes approximately 84 per cent of total short-circuit current for 100 per cent connected motors

V.	Transformer Impedance Per Cent									
	4.0	4.0	5.0	5.0	5.0	5.0	5.0	5.5	5.5	5.5	5.5

VI. Magnetic Air Circuit Breakers Available

Type	Interrupting Rating (RMS Amperes)	Standard Continuous-Current Trip Ratings (Amperes)
15-AE1A	15,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225
25-AE1B	25,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600
50-AL-2	50,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600, 800, 1,000, 1,200, 1,600
75-AL-2	75,000	2,000, 2,500, 3,000
100-AL-2	100,000	4,000, 5,000, 6,000

to 500,000 kva in 15-kv metal-clad equipments. The vertical-lift removable type of breaker is standard in these equipments. Instruments, meters, and relays, mounted on steel panels, may be part of the equipment.

The metal-clad switchgear may have only one breaker as shown in Figure 5. Again there may be two breakers to meet the requirements of the primary-selective scheme as shown in Figure 6. A modification of the primary-selective scheme comprises two breaker positions and only one breaker, as shown in Figure 7. One removable breaker is arranged so that it can be inserted in either of the two breaker positions. This, of course, results in a lower installed cost and has proved attractive for some applications.

In place of the high-voltage metal-enclosed switchgear a set of three flange-mounted gang-operated oil-filled cutout switches may be used, as shown in Figure 8. This type of switch is rated five kilovolts, 250 amperes continuous. Most applications of the switch have utilized the switch as a disconnect only, with copper disconnecting blades in place of fuse links. The cutouts may be fused in the smaller ratings, when co-ordination with the low-voltage circuit breakers can be obtained such that the low-voltage circuit breakers will clear secondary faults before primary fuses are damaged. Cutouts may be fused up to 100 amperes at 5 kv and 200 amperes at 2.5 kv, with inter-

Load-Center Unit-Substation Application Table IV. 480 Volts, Three-Phase

For Use in Connection With Load-Center Unit Substations Only

Available Primary 3-Phase Short-Circuit Kva	Transformer Kilovolt-Ampere Rating											
	100	150	200	300	450	500	600	750	1,000	1,200	1,500	2,000
	Normal Current (Amperes)											
	120	181	241	361	542	601	722	902	1,203	1,443	1,804	2,406
I. For Transformer Main Low-Voltage Breakers (Selection Based on Adequate Interrupting and Current Rating)												
25,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
50,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
75,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
100,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
150,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
250,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
500,000	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
Unlimited	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2	75-AL2
II. For Transformer Multiple Low-Voltage Breakers (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)												
25,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	75-AL2	75-AL2
III. For Branch Circuit Breakers Co-ordinated With Transformer Main Low-Voltage Breaker (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)												
25,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B
50,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B
75,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B
100,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2
IV. Total Low-Voltage Short-Circuit Current—RMS Amperes (Impedance As Given in Table V, Total Connected Motor Kilovolt-Amperes Equals 100 Per Cent of Transformer Rating)												
25,000	4,020	5,810	6,390	9,080	12,700	13,800	15,800	17,800	21,800	24,700	28,600	34,400
50,000	4,180	6,150	6,760	9,860	14,200	15,500	18,200	20,600	26,100	30,000	35,600	43,800
75,000	4,250	6,270	6,910	10,200	14,800	16,300	19,200	21,900	28,100	32,600	39,100	49,000
100,000	4,280	6,340	6,980	10,300	15,100	16,700	19,700	22,500	29,200	34,200	41,300	52,200
150,000	4,310	6,400	7,050	10,500	15,500	17,100	20,300	23,300	30,400	35,900	43,800	56,200
250,000	4,330	6,460	7,120	10,600	15,800	17,500	20,800	24,000	31,500	37,400	46,000	59,900
500,000	4,350	6,500	7,160	10,700	16,000	17,800	21,200	24,500	32,400	38,700	47,900	63,000
Unlimited	4,370	6,540	7,200	10,800	16,300	18,100	21,700	25,000	33,400	40,000	50,100	66,800
V	Transformer Impedance Per Cent											
	4.0	4.0	5.0	5.0	5.0	5.0	5.0	5.5	5.5	5.5	5.5	5.5

1. For different voltage base, multiply values in Table IV by the ratio: Standard voltage/New voltage
2. Transformer contributes approximately 84 per cent of total short-circuit current for 100 per cent connected motors

VI. Magnetic Air Circuit Breakers Available

Type	Interrupting Rating (RMS Amperes)	Standard Continuous-Current Trip Ratings (Amperes)
15-AE1A	15,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225
25-AE1B	25,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600
50-AL-2	50,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600, 800, 1,000, 1,200, 1,600
75-AL-2	75,000	2,000, 2,500, 3,000
100-AL-2	100,000	4,000, 5,000, 6,000

rupting ratings of 5,000 amperes rms at 5 kv, and 10,000 amperes rms at 2.5 kv.

For a five-kilovolt primary-selective system two sets of cutouts are available in a free-standing metal house. All of the cutouts have gang-operating mechanisms, usually interlocked so that only one set can be closed at a time. This arrangement is shown in Figure 9.

A liquid-filled 15-kv disconnecting switch arrangement is shown in Figure 10. This switch is the one developed for network transformers. It is suitable for circuits with normal currents up to 200 amperes. The switch may be filled with either oil or Pyranol, depending upon the application.

In addition to these high-voltage arrangements, the load-center unit substation may be equipped with a cable terminal and junction box without any disconnecting means. These may be oil- or Pyranol-filled for either 5-kv or 15-kv circuits, or air-filled for 5-kv circuits. This arrangement is shown in Figure 11.

The transformer section itself is available in all standard three-phase kilovolt-ampere ratings from 100 to 2,000 kva. Transformers rated above 250 kva are equipped with four 2½ per cent taps spaced two above and two below normal high voltage. Automatic voltage-regulating equipment is not included in the transformer section, because there has been no demand for this equipment.

Load-Center Unit-Substation Application Table V. 600 Volts, Three-Phase

For Use in Connection With Load-Center Unit Substations Only

Available Primary 3-Phase Short-Circuit Kva	Transformer Kilovolt-Ampere Rating											
	100	150	200	300	450	500	600	750	1,000	1,200	1,500	2,000
	Normal Current (Amperes)											
	96.2	144	192	289	433	481	577	722	962	1,154	1,444	1,925
I. For Transformer Main Low-Voltage Breaker (Selection Based on Adequate Interrupting and Current Rating)												
25,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2	75-AL2
II. For Transformer Multiple Low-Voltage Breakers (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)												
25,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2
50,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2
75,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
100,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
150,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2
250,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	50-AL2
500,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2	50-AL2	50-AL2	75-AL2
III. For Branch Circuit Breakers Co-ordinated With Transformer Main Low-Voltage Breaker (Selection Based on Adequate Interrupting Rating Only. Check Current Ratings From Table V)												
25,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A
50,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B
75,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B
100,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B
150,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B
250,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B
500,000	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2
Unlimited	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	15-AE1A	25-AE1B	25-AE1B	50-AL2
IV. Total Low-Voltage Short-Circuit Current—RMS Amperes (Impedances As Given in Table V, Total Connected Motor Kilovolt-Amperes Equals 100 Per Cent of Transformer Rating)												
25,000	3,210	4,640	5,100	7,260	10,100	11,000	12,600	14,200	17,500	19,800	22,900	27,500
50,000	3,350	4,920	5,400	7,870	11,300	12,400	14,500	16,500	20,900	24,100	28,500	35,100
75,000	3,390	5,010	5,520	8,110	11,800	13,000	15,300	17,500	22,500	26,100	31,300	39,200
100,000	3,420	5,060	5,580	8,250	12,100	13,400	15,800	18,100	23,300	27,400	33,100	41,800
150,000	3,450	5,120	5,640	8,380	12,400	13,700	16,300	18,700	24,300	28,700	35,100	45,000
250,000	3,460	5,170	5,680	8,490	12,600	14,000	16,700	19,200	25,300	29,900	36,900	47,900
500,000	3,480	5,200	5,730	8,570	12,800	14,200	17,000	19,600	25,900	31,000	38,400	50,400
Unlimited	3,490	5,220	5,760	8,660	13,000	14,400	17,300	20,000	26,700	32,300	40,100	53,500
V. Transformer Impedance Per Cent	4.0	4.0	5.0	5.0	5.0	5.0	5.0	5.5	5.5	5.5	5.5	5.5
VI. Magnetic Air Circuit Breakers Available												
Type	**Interrupting Rating (RMS Amperes)**	**Standard Continuous-Current Trip Ratings (Amperes)**										
15-AE1A	15,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225										
25-AE1B	25,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600										
50-AL-2	50,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 400, 450, 500, 550, 600, 800, 1,000, 1,200, 1,600										
75-AL-2	75,000	2,000, 2,500, 3,000										
100-AL-2	100,000	4,000, 5,000, 6,000										

1. For different voltage base, multiply values in Table IV by the ratio: Standard voltage/New voltage
2. Transformer contributes approximately 84 per cent of total short-circuit current for 100 per cent connected motors

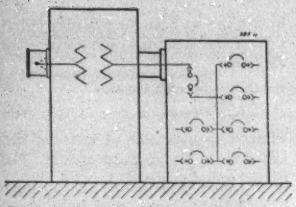

Figure 11. Load-center unit substation with primary junction box only

The transformer may be liquid-filled with the medium of cooling either oil or Pyranol. The Pyranol coolant is generally preferred for both indoor and outdoor load-center applications, but oil-filled transformers are often used outdoors. The Pyranol transformer has been a big factor in the development of the load-center distribution idea. Pyranol will not burn, and thus the Pyranol load-center unit substation can be located indoors near production centers without an expensive fireproof vault.

The dry type of transformer, cooled by the natural circulation of air through the windings, has also been developed for load-center unit substations.

Metal enclosed low-voltage switchgear is used in load-center unit substations. Usually, a number of branch circuits radiate from a single load-center unit substation. These branch circuits are controlled by means of air circuit breakers, mounted in compartments in the low-voltage switchgear. Air circuit breakers, with current interrupting ratings of 15,000, 25,000, 50,000, 75,000, and 100,000 amperes rms, are available in these equipments. The breakers may be either manually or electrically operated. The majority of the applications have required the use of manually operated breakers only. All circuit breakers operate with a time delay on overload currents, but trip instantaneously on short circuit. The breakers may be of either the stationary or the draw-out type. The draw-out type has been used extensively because of the interchangeability of draw-out breakers, which is an important factor in avoiding production delays during routine inspection. The breakers are available in stacks of one, two, three, and four high, depending on the size of the breaker. Two or more stacks can be located side by side to give the required number of breakers. These equipments are used with radial types of systems. For network applications, the standard network protector replaces two of the air circuit breakers in one of the stacks.

Load-Center Unit-Substation Application Tables

The interrupting rating of a circuit breaker is the maximum current which it is able to interrupt adequately and safely. It is important to use circuit breakers of adequate interrupting rating on load-center unit-substation circuits, as well as on any other circuits in which circuit breakers are used, in order to assure reduced arcing time with minimum damage to equipment when faults do occur. Contrary to a former rather widespread belief that low-voltage circuits will not produce short-circuit currents in excess of 20,000 amperes, tests have shown that short-circuit currents of several times this value may occur.[2] These values can be predicted by calculation with reasonable accuracy. Tentative rules for the calculation of these currents have been established by the AIEE.[3]

The load-center unit-substation application tables given here are based on the occurrence of a three-phase secondary fault near the terminals of the unit substation. The only source of power to the secondary, except for secondary motors, is assumed to be through the load-center unit substation. It is assumed that the total connected motor kilovolt-amperes will not exceed 50 per cent of the transformer rating on 208/120-volt systems and 100 per cent of the transformer kilovolt-ampere rating on 240-, 480-, and 600-volt systems. See Tables II, III, IV, and V.

The calculations for the short-circuit currents are based on the following:

1. Systems with voltages of 208/120, 240, 480, and 600 volts, because these are ASA standard voltages given in tentative standards *C*-57.1, dated March 1940.

2. Transformer reactances have been selected to give the most economical balance between transformer reactance and circuit-breaker interrupting rating consistent with reasonable voltage regulation. The actual values of reactance are indicated in the tables.

3. Calculations are based on proposed AIEE standard rules, that is: the symmetrical three-phase rms short-circuit current is increased by a factor of 1.25 to allow for an average d-c component. For the motor contribution, 50 per cent connected motor kilovolt-amperes is assumed to be capable of supplying a short-circuit current of 2.5 times the normal full load current of the transformer, and 100 per cent connected motor kilovolt-amperes is assumed to be capable of supplying a short-circuit current of 5.0 times the normal current of the transformer.

Standard load-center unit-substation breaker arrangements are shown on Figures 12, 13, and 14. The basis of selection of the magnetic air circuit breaker used in the tables for these three arrangements are as follows:

Any air circuit breaker directly connected to the power source (A' or A) can be used up to 100 per cent of its interrupting rating only.

Any magnetic circuit breaker (B) which is backed up by a properly co-ordinated main breaker of adequate interrupting rating (A') can be used up to 200 per cent of its interrupting rating.

Breakers arranged as in Figure 14 are said to be in "cascade."[4] The back-up breaker (A') must be properly co-ordinated with the cascaded breaker (B), so that the breaker (A') will trip instantaneously on short-circuit currents in excess of the interrupting rating of the breaker (B).

The cascade arrangement of air circuit breakers shown in Figure 14 often results in a lower-cost substation than is obtained with the arrangement shown in Figure 13. However, the cascade arrangement has the limitation that a heavy short circuit on any of the branch breakers may open the main air circuit breaker and result in an interruption of service to all of the branch feeders. Thus, when lower cost can be obtained with the cascade arrangement, careful consideration should always be given to the value of continuity of service.

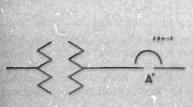

Figure 12. For main breaker A'

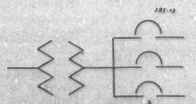

Figure 13. For branch breakers A

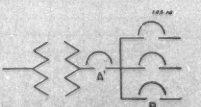

Figure 14. For cascaded branch breakers B

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High-Frequency Coaxial-Line Calculations

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Synopsis: Coaxial cables insulated with solid dielectric are used for transmitting electric energy over wide ranges of frequency. During the development of such cables it was important to be able to predict the characteristics of finished cable by calculations based upon the known dimensions and physical properties of the conductors and the insulation. Many comparatively simple formulas were known to be valid at high frequency, but their applicability at lower frequencies was questioned.

In the first part of this paper we have presented:

1. The general relations which hold under all conditions of operation.

2. The conditions under which "skin-effect" tables offer a convenient method for obtaining values of resistance and inductance, as well as the conditions under which relatively simple equations for these quantities are sufficiently accurate.

3. The conditions under which the complete expression for attenuation may be considerably simplified to the form generally used in high frequency practice.

In the second part of the paper we have presented formulas and graphs for the ratio of terminal voltages as a function of the phase angle of the line for several types of load for both dissipationless and dissipative lines. These relations are helpful in understanding observed voltage variations with frequency caused by reflections, particularly on short lengths of line.

In the third part of the paper a derivation is indicated leading to a general equation for the efficiency of transmission. Simplifications are made which are often applicable in practice, and curves are plotted showing the effect of mismatch in reducing efficiency.

A. Transmission-Line Relations

THE electrical characteristics of a concentric transmission line with distributed constants are given by the relations

$$\text{Propagation coefficient} = \gamma = \alpha + j\beta = \sqrt{ZY} \quad (1)$$

$$\text{Characteristic impedance} = Z_0 = \sqrt{Z/Y} \quad (2)$$

where

α = attenuation per centimeter length of line
β = phase shift per centimeter length of line
$Z = R + j\omega L = z\angle\theta_z$ = impedance per centimeter length
$Y = G + j\omega C = y\angle\theta_y$ = admittance per centimeter length
R = series resistance per centimeter length
L = series inductance per centimeter length
G = parallel conductance per centimeter length
C = parallel capacitance per centimeter length

Separating real and imaginary terms in equation 1 we have[1]

$$\alpha = \sqrt{zy}\cdot\cos\tfrac{1}{2}(\theta_z+\theta_y) = A\cos(\theta/2) \quad (3)$$

$$\beta = \sqrt{zy}\cdot\sin\tfrac{1}{2}(\theta_z+\theta_y) = A\sin(\theta/2) \quad (4)$$

or in terms of the distributed properties of the line

$$\alpha = \sqrt[4]{(RG-\omega^2LC)^2+(G\omega L+R\omega C)^2}\cdot \cos\tfrac{1}{2}\left[\tan^{-1}\left(\frac{G\omega L+R\omega C}{RG-\omega^2LC}\right)\right] \quad (5)$$

$$\beta = \sqrt[4]{(RG-\omega^2LC)^2+(G\omega L+R\omega C)^2}\cdot \sin\tfrac{1}{2}\left[\tan^{-1}\left(\frac{G\omega L+R\omega C}{RG-\omega^2LC}\right)\right] \quad (6)$$

Also since it is the magnitude of characteristic impedance which is of interest in cable design we have from equation 2

$$Z_0^2 = (z/y) = \sqrt{(RG+\omega^2LC)^2+(G\omega L-R\omega C)^2}/(G^2+\omega^2C^2) \quad (7)$$

Equations 1 through 7 are general for any frequency and for any transmission line to which a sinusoidal voltage is applied, so long as the proper coefficients R, L, G, and C are used. We shall therefore consider next the relations by which these four quantities can be calculated.

1. Admittance Per Centimeter Length

Our past experience[2] has shown the convenience of expressing the admittance of a capacitor of any shape as follows:

$$Y = G + j\omega C = \omega C_v(\epsilon'' + j\epsilon')$$

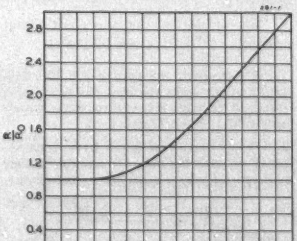

Figure 1. Ratio of a-c to d-c resistance R/R_0 as a function of the ratio of thickness to depth of penetration t/y for a cylindrical outer conductor in a coaxial line

from which we have the following definitions of unit quantities characterizing the dielectric

$$\epsilon' = C/C_v = \text{dielectric constant} \quad (8)$$

$$\epsilon'' = G/\omega C_v = \text{loss factor} \quad (9)$$

where C_v = capacitance of the same size and shape of electrodes in vacuum. For coaxial cylinders of radii r_1 and r_2

$$C_v = 0.241\times10^{-13}/\log_{10}(r_2/r_1) \text{ farads/cm} \quad (10)$$

$$\therefore C = 0.241\times10^{-13}\epsilon'/\log_{10}(r_2/r_1) \text{ farads/cm} \quad (11)$$

and

$$G = 1.515\times10^{-13}f\epsilon''/\log_{10}(r_2/r_1) \text{ mhos/cm} \quad (12)$$

Both coefficients ϵ' and ϵ'' may vary with frequency and must be known or assumed for the insulating material for the frequency range being considered.

2. Impedance Per Centimeter Length

The resistance and the inductance of both the inner and outer conductors will vary with frequency because of "skin effect." Therefore there are no simple general relations which can be used at all frequencies.

If the inner conductor is a round wire, the skin effect at low frequencies can be obtained from Table I, which has been worked out from complicated exact formulas.[3-5] This table gives the ratios R/R_0 and L/L_0 (where R_0 and L_0 represent the resistance and inductance at zero frequency) as functions of the parameter

$$x = 2\pi r_1\sqrt{2\mu f/\rho} \quad (13)$$

For copper $\mu = 1$, $\rho = 1{,}724$ abohmcentimeters and

$$x = 0.214r_1\sqrt{f} \quad (14)$$

The depth of penetration y is defined as the thickness of shell to give the same d-c resistance and is given by the relation

$$y = \sqrt{\rho/2\pi\sqrt{\mu f}} \quad (15)$$

or

$$y = 6.62/\sqrt{f} \text{ centimeter (for copper)} \quad (16)$$

If the outer conductor is a hollow cylinder of thickness t (where $r_2 > 5t$), the corresponding values for the ratio R/R_0 were worked out by J. R. Whinnery and are given in Figure 1 as a function of t/y where y is the depth of penetration[6] (equation 16).

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The resistances of the inner and outer conductors are added together to give the total resistance per unit length

$$R_l = 0.548\times10^{-6}\left[\underbrace{\left(\frac{R/R_0}{r_1^2}\right)}_{\text{inner}}+\underbrace{\left(\frac{R/R_0}{2r_2}\right)}_{\text{outer}}\right]$$

ohm per centimeter length (17)

where (R/R_0) for the inner conductor is taken from Table I and (R/R_0) for the outer conductor is taken from Figure 1.

If the parameter x is greater than 20, a condition which is normally satisfied at high frequency, then the depth of penetration is so small that it is not necessary to use Table I. Likewise if t/y for the outer conductor is greater than 3, then the inner and outer resistances vary inversely as the radii of the conductors as follows:[3]

$$R = \sqrt{\rho\mu f}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)\times10^{-9}$$ ohm per centimeter length (18)

For copper conductors this reduces to

$$R = 4.15\times10^{-8}\sqrt{f}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

ohm per centimeter length (19)

If the inner conductor is stranded and the outer conductor braided, the above calculations will be optimistic, since they do not take into account contact resistance between strands, which may be very important, especially if the copper is dirty or becomes corroded or oxidized. After considerably more empirical evidence is obtained, perhaps multiplying factors can be assigned to indicate a proportionate increase of resistance above the values given by equation 17 caused by stranded inner conductors and braided or wrapped outer conductors. For example, we have found by experience that in coaxial cables built with 0.2-centimeter-diameter inner conductors the attenuation is about one decibel per 100 feet greater at 315 megacycles with a stranded inner conductor than it is with a solid inner conductor.

The expression for inductance[3] at zero frequency is

$$L_0 = \left\{4.6\log_{10}(r_2/r_1)+0.5+\left[\frac{4.6r_3^4}{(r_3^2-r_2)^2}\log_{10}(r_3/r_2)-\frac{3r_3^2-r_2^2}{2(r_3^2-r_2^2)}\right]\right\}\times$$

10^{-9} henry per centimeter (20)

where r_3 = outer radius of outer conductor in centimeters. The first term gives the inductance between the conductors; the second and third terms give the inductance within the inner and outer conductors respectively.

To show the relative magnitudes of the several terms in equation 20, assume the physical dimensions for cable 1 for which the complete calculations are shown in Table II (next section). Substituting in equation 20 we obtain:

$$L_0 = [2.62+0.5+(8.9092-8.8752)]\times10^{-9}$$ henry per centimeter

Both terms of the inductance within the outer conductor were obtained using five-place logarithms, and the numbers have been recorded in order to indicate that the calculation involves a small difference between two nearly equal quantities. However, this also demonstrates that the inductance within the outer conductor may be neglected in comparison with the other terms of equation 20. Since the inductance within the conductors decreases as frequency increases, we have

$$L = [4.6\log_{10}(r_3/r_1)+0.5(L/L_0)]\times10^{-9}$$ henry per centimeter (21)

where L/L_0 for the inner conductor is obtained from Table I. At high frequencies the inductance within the inner conductor also becomes negligible so that we may use the simple relation

$$L = 4.6\log_{10}(r_3/r_1)\times10^{-9}$$ henry per centimeter (22)

3. Approximations Leading to Simplified Formulas

In order to show the conditions under which the general equations 1–7 can be reduced to the commonly used simplified forms, we have shown in Table II the important terms involved for two cables at two frequencies.

Table II shows that at 315 megacycles items 10, 12, and 13 are negligible compared to item 11, that is:

$$\omega^2LC \gg RG \quad (23)$$

and

$$(\omega^2LC)^2 \gg (G\omega L+R\omega C)^2 \quad (24)$$

If equation 5 is simplified assuming the above inequalities

$$\alpha \cong \sqrt{\omega^2LC}\cdot\cos\frac{\theta}{2} \cong \sqrt{\omega^2LC}\sin\left(\frac{\delta}{2}\right) \cong \sqrt{\omega^2LC}\left(\frac{\delta}{2}\right) \quad (25)$$

where

$$\theta = 180^\circ-\delta \quad (26)$$

and

$$\tan\delta \cong \left(\frac{G\omega L+R\omega C}{\omega^2LC}\right) \cong \sin\delta \cong \delta \quad (27)$$

or

$$\alpha \cong (G\omega L+R\omega C)/2\sqrt{\omega^2LC} \quad (28)$$

or

$$\alpha \cong \alpha_d+\alpha_c \cong {}^1/_2G\sqrt{L/C}+{}^1/_2R\sqrt{C/L} \quad (29)$$

where α_d = contribution to attenuation by dielectric loss only

and α_c = contribution to attenuation by copper loss only

α_d may also be obtained directly from equation 5 by assuming $R=0$, and α_c may be obtained by assuming $G=0$ in this same equation. Therefore, we have shown that under the conditions for which equations 23 and 24 are true, the contributions to attenuation of the copper losses and the dielectric losses may be calculated separately and considered to be additive.

Substituting in equation 25 the rela-

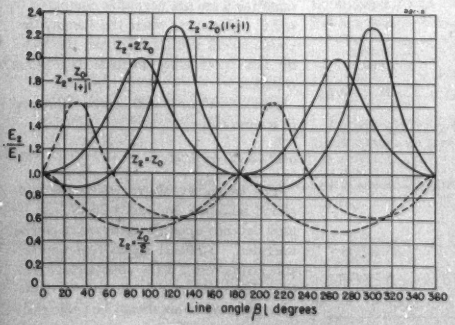


Figure 2. Ratio of receiving to sending voltage E_2/E_1 as a function of line angle βl for several values of terminating impedance Z_2 in a dissipationless line

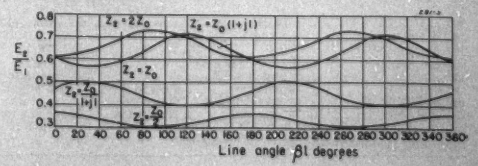
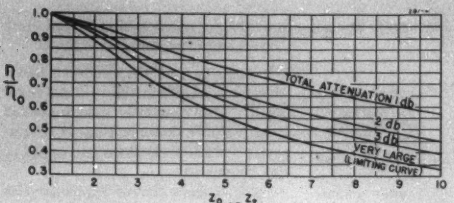


Figure 3. Ratio of receiving to sending voltage E_2/E_1 as a function of line angle βl for several values of terminating impedance Z_2 for a line having a total attenuation of six decibels



$$\eta = \frac{1}{\cosh 2\alpha l + \frac{1}{2}\left(\frac{Z_0}{Z_2}+\frac{Z_2}{Z_0}\right)\sinh 2\alpha l}$$

Figure 4. Efficiency of transmission for several values of total attenuation for a range of values of mismatch

$\alpha l = 0.115 \times$ total attenuation of line in decibels

Z_0 = Surge impedance (resistive)
Z_2 = Load impedance (resistive)
$\eta_0 = e^{-2\alpha l}$ when $Z_0 = Z_2$

Table I. Skin-Effect Resistance and Inductance Ratios for Solid Round Wires

x	R/R_0	L/L_0	x	R/R_0	L/L_0
0.0	1.00000	1.00000	2.5	1.17538	0.91347
0.1	1.00000	1.00000	2.6	1.20056	0.90126
0.2	1.00001	1.00000	2.7	1.22753	0.88825
0.3	1.00004	0.99998	2.8	1.25820	0.87451
0.4	1.00013	0.99993	2.9	1.28644	0.86012
0.5	1.00032	0.99984	3.0	1.31809	0.84517
0.6	1.00067	0.99966	3.5	1.49202	0.76550
0.7	1.00124	0.99937	4.0	1.67787	0.66632
0.8	1.00212	0.99894	4.5	1.86275	0.61563
0.9	1.00340	0.99830	5.0	2.04372	0.55597
1.0	1.00519	0.99741	6.0	2.39359	0.46521
1.1	1.00758	0.99821	7.0	2.74319	0.40021
1.2	1.01071	0.99465	8.0	3.09445	0.55107
1.3	1.01470	0.99266	9.0	3.44638	0.31257
1.4	1.01988	0.99017	10.0	3.79857	0.28162
1.5	1.02582	0.98711	11.0	4.15100	0.25622
1.6	1.03323	0.98342	12.0	4.50358	0.23501
1.7	1.04203	0.97904	13.0	4.85831	0.21703
1.8	1.05240	0.97390	14.0	5.20915	0.20160
1.9	1.06440	0.96795	15.0	5.56205	0.18822
2.0	1.07818	0.96113	20.0	7.32767	0.14128
2.1	1.09375	0.95343	25.0	9.09412	0.11307
2.2	1.11126	0.94482	30.0	10.88101	0.09424
2.3	1.13069	0.93527	40.0	14.39545	0.07069
2.4	1.15207	0.92482	50.0	17.93032	0.05656
			60.0	21.46541	0.04713
			80.0	28.53593	0.03535
			100.0	35.60666	0.02828
					0.00000

$$\lim_{x \to \infty}\left(\frac{R}{R_0}\right) = 0.354x$$

Table II. Important Items in Equation 5

	Cable 1	Cable 2		
Cable specifications				
r_1	0.1028 cm		0.325 cm	
r_2	0.381 cm		1.27 cm	
l	0.025 cm		0.025 cm	
ϵ'	2.04		2.65	
ϵ''	0.001		0.0089	
Frequency (cycles per second)	2.5×10^4	3.15×10^8	2.5×10^4	3.15×10^8
1. C (eq 11)	1.017×10^{-12}	1.017×10^{-12}	1.08×10^{-12}	1.08×10^{-12}
2. G (eq 12)	6.65×10^{-11}	8.39×10^{-3}	1.85×10^{-10}	2.34×10^{-3}
3. x (eq 14)	3.48	(590)	11.0	(1,230)
4. R/R_0	1.485	(209)	4.15	(435)
5. R (eq 17)	1.06×10^{-4}		0.303×10^{-4}	
6. R (eq 19)	(0.81×10^{-4})	91.0×10^{-4}	(0.254×10^{-4})	28.5×10^{-4}
7. L/L_0	0.769		0.256	
8. L (eq 20)	3.00×10^{-9}		2.85×10^{-9}	
9. L (eq 22)	(2.62×10^{-9})	2.62×10^{-9}	(2.72×10^{-9})	2.72×10^{-9}
10. RG	7.05×10^{-15}	7.63×10^{-9}	5.60×10^{-15}	6.67×10^{-9}
11. ω^2LC	7.52×10^{-11}	1.045×10^{-3}	7.58×10^{-11}	1.15×10^{-3}
12. $G\omega L$	3.13×10^{-14}	4.35×10^{-4}	8.27×10^{-14}	1.26×10^{-3}
13. $R\omega C$	1.69×10^{-11}	1.83×10^{-3}	5.14×10^{-12}	6.09×10^{-4}
14. A (eqs 3 and 5)	8.8×10^{-4}		8.7×10^{-4}	
15. δ (eqs 3 and 5)	167.3		176.1	
16. $\cos(\theta/2)$	0.11		0.034	
17. α (eq 5)	9.69×10^{-7}		2.96×10^{-7}	
18. α_c (eq 30)	(8.0×10^{-7})	9.0×10^{-3}	(2.52×10^{-7})	2.83×10^{-3}
19. α_d (eq 32)	(1.7×10^{-9})	2.14×10^{-3}	(4.67×10^{-9})	5.9×10^{-3}
20. α (eq 29)	(8.02×10^{-7})	11.1×10^{-3}	(2.57×10^{-7})	8.7×10^{-3}
21. $N_{db}/100$ ft	2.56×10^{-3}	2.94	7.35×10^{-4}	2.31
Error using approximate equation	-17%		-13%	

tions for R, L, C, and G given in equations 19, 22, 11, and 12 respectively, we have

$$\alpha_c \cong 1.50\times10^{-10}\sqrt{f\epsilon'}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)/\log_{10}\times (r_2/r_1) \text{ neper per centimeter} \quad (30)$$

or

$$N_c \cong 3.98\times10^{-4}\sqrt{f\epsilon'}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)/\log_{10}\times (r_2/r_1) \text{ decibel per 100 feet} \quad (31)$$

and

$$\alpha_d \cong 1.05\times10^{-10} f\epsilon''/\sqrt{\epsilon'} \text{ neper per centimeter} \quad (32)$$

or

$$N_d \cong 2.78\times10^{-5} f\epsilon''/\sqrt{\epsilon'} \text{ decibel per 100 feet} \quad (33)$$

where

$$N_{\text{total}} \cong N_c(\text{copper loss only}) + N_d(\text{dielectric loss only}) \quad (34)$$

If equation 7 is simplified assuming the inequalities, equations 23 and 24, we have

$$Z_0 = \sqrt{L/C} = 138\log_{10}(r_2/r_1)/\sqrt{\epsilon'} \quad (35)$$

which is the expression usually used for characteristic impedance at high frequency.

Likewise assuming the inequalities, equations 23 and 24, equation 6 reduces to

$$\beta \cong \sqrt{\omega^2 LC} \cong \omega C Z_0 \quad (36)$$

The trigonometric term in equation 5 is important, because it is zero if the losses are zero. Thus an approximate evaluation at high frequencies for this term (although it is small) leads to the useful relation given in equation 25.

On the other hand, the trigonometric term in equation 6 is unimportant, since it is unity for zero losses, and losses at high frequencies simply decrease this term slightly below unity. The recognized effect of high losses in increasing the phase constant must appear, because some of the factors in the first term of equation 6 are not negligible compared to ω^2LC. However, when the inequalities, equations 23 and 24, are true, the losses do not appreciably increase the phase constant.

Similarly equation 29 can be expressed in terms of Z_0

$$\alpha \cong (GZ_0/2) + (R/2Z_0) \quad (37)$$

The frequency above which the simplified relations, equations 25–37, can be used depends upon the error which can be tolerated. Table II shows that appreciable errors result if the approximate relations are used at 25 kilocycles. However these relations should be sufficiently

accurate for frequencies in the broadcast band or above.

B. Voltage Relations

In a transmission line of length l, having uniformly distributed constants, the complex expression for the ratio of the voltage at the sending end E_1 to the voltage at the receiving end E_2 is given by the relation

$$\frac{E_1}{E_2} = \cosh \gamma l + \frac{Z_0}{Z_2} \sinh \gamma l \qquad (38)$$

which upon expansion becomes

$$\frac{E_1}{E_2} = \left(\cosh \alpha l + \frac{Z_0}{Z_2} \sinh \alpha l\right) \cos \beta l + j\left(\sinh \alpha l + \frac{Z_0}{Z_2} \cosh \alpha l\right) \sin \beta l \qquad (39)$$

where Z_0 = surge impedance of line
and Z_2 = impedance across receiving end of line

From this general relation several special cases lead to usable simplifications.

1. Dissipationless Case

$$\left(\begin{matrix} G = R = \sinh \alpha l = 0 \\ \cosh \alpha l = 1,\ Z_0 = \text{real} \end{matrix}\right)$$

(*a*). Assuming pure resistance termination, (Z_2 = real), the absolute value of the voltage ratio given by equation 39 can be reduced to

$$\left|\frac{E_1}{E_2}\right| = \sqrt{\frac{1}{2}\left[1+\left(\frac{Z_0}{Z_2}\right)^2\right] + \frac{1}{2}\left[1-\left(\frac{Z_0}{Z_2}\right)^2\right] \cos 2\beta l} \qquad (40)$$

(*b*). Assuming complex termination ($Z_2 = \sqrt{R_2^2 + x_2^2}$) equation 39 becomes

$$\left|\frac{E_1}{E_2}\right| = \sqrt{\frac{1}{2}\left[1+\left(\frac{Z_0}{Z_2}\right)^2\right] + \frac{1}{2}\left[1-\left(\frac{Z_0}{Z_2}\right)^2\right] \cos 2\beta l + \frac{X_2 Z_0}{Z_2^2} \sin 2\beta l} \qquad (41)$$

The last two equations have been used to calculate the data given in Figure 2 which show the ratio of receiving to sending voltage E_2/E_1 for the dissipationless line for several types of load impedance.

2. Dissipative Line

For a line having high losses, particularly at low frequency, the surge impedance (Z_0) may have an appreciable reactive component. But in lines for which equations 23 and 24 apply, the reactive component of Z_0 is negligible as indicated by equation 35.

(*a*). Assuming pure resistance termination (Z_2 = real) equation 39 reduces to

$$\left|\frac{E_1}{E_2}\right| = \sqrt{\frac{Z_0}{Z_2} \sinh 2\alpha l + \frac{1}{2}\left[1+\left(\frac{Z_0}{Z_2}\right)^2\right] \cosh 2\alpha l + \frac{1}{2}\left[1-\left(\frac{Z_0}{Z_2}\right)^2\right] \cos 2\beta l} \qquad (42)$$

(*b*). Assuming complex termination, ($Z_2 = \sqrt{R_2^2 + x_2^2}$) equation 39 becomes

$$\left|\frac{E_1}{E_2}\right| = \sqrt{\frac{RZ_0}{Z_2^2} \sinh 2\alpha l + \frac{1}{2}\left[1+\left(\frac{Z_0}{Z_2}\right)^2\right] \cosh 2\alpha l + \frac{1}{2}\left[1-\left(\frac{Z_0}{Z_2}\right)^2\right] \cos 2\beta l + \frac{X_2 Z_0}{Z_2^2} \sin 2\beta l} \qquad (43)$$

Figure 3 shows plots of the last two relations for a total attenuation of six decibels for the same terminating impedances as were used in Figure 2.

3. High-Loss Lines

As the total attenuation is increased, the variation in the ratio of E_2/E_1 with line angle decreases. For a line having an attenuation of 20 decibels, $\alpha l = 2.3$, and there is only about two per cent error in the relation

$$\cosh \alpha l = \sinh \alpha l = {}^1/_2 \epsilon^{\alpha l} \qquad (44)$$

Under these conditions equation 39 can be further simplified.

(*a*). Assuming pure resistance termination (Z_2 = real)

$$\left|\frac{E_1}{E_2}\right| = \frac{\epsilon^{\alpha l}}{2}\left(1+\frac{Z_0}{Z_2}\right) \qquad (45)$$

(*b*). Assuming complex termination ($Z_2 = \sqrt{R_2^2 + x_2^2}$)

$$\left|\frac{E_1}{E_2}\right| = \frac{\epsilon^{\alpha l}\sqrt{Z_2^2 + 2R_2 Z_0 + Z_0^2}}{2Z_2} \qquad (46)$$

The simplest relation for the ratio E_1/E_2 is obtained when the line is terminated in a load which is exactly equal to its surge impedance ($Z_2 = Z_0$) in which case

$$\left|\frac{E_1}{E_2}\right| = \epsilon^{\alpha l} \qquad (47)$$

Equations 38–47 were derived in order to interpret voltage data taken during measurements of attenuation in commercial high-frequency solid dielectric coaxial cables.[7]

C. Efficiency of Transmission

The efficiency of transmission is defined as the ratio of output to input power; however, the mathematical expression is simpler if the reciprocal relations are used. The most general case is that for which both the characteristic and load impedances of the line are complex. This case has been solved by E. W. Hamlin (unpublished report, General Electric Company). The essential steps and final relation are:

$$\text{Characteristic impedance} = Z_0 = R_0 + jX_0 \qquad (48)$$

$$\text{Load impedance} = Z_2 = R_2 + jX_2 \qquad (49)$$

then the input impedance is given by[8]

$$Z_1 = Z_0\left[\frac{Z_2 \cosh \gamma l + Z_0 \sinh \gamma l}{Z_0 \cosh \gamma l + Z_2 \sinh \gamma l}\right] \qquad (50)$$

and the input current as a function of the load current is given by

$$I_1 = \frac{I_2}{Z_0}(Z_0 \cosh \gamma l + Z_2 \sinh \gamma l) \qquad (51)$$

$$\text{The input power} = |I_1|^2 \times \text{real component of } Z_1 \qquad (52)$$

$$\text{and the output power} = |I_2|^2 R_2 \qquad (53)$$

Hamlin takes the ratio of these last two relations and upon expansion and simplification obtains the general equation:

$$\frac{W_1}{W_2} = \frac{R_0}{R_2|Z_0|^2}[(R_2R_0 + X_2X_0)\cosh 2\alpha l + {}^1/_2(|Z_2|^2 + |Z_0|^2)\sinh 2\alpha l] + \frac{X_0}{R_2|Z_0|^2}[(X_0R_2 - X_2R_0)\cos 2\beta l + {}^1/_2(|Z_2|^2 - |Z_0|^2)\sin 2\beta l] \qquad (54)$$

As a simplification of equation 54, let $X_0 = 0$, that is, assume that the reactive component of the characteristic impedance is negligible, as is usually the case in high-frequency transmission. Then equation 54 reduces to

$$\frac{W_1}{W_2} = \cosh 2\alpha l + {}^1/_2\left(\frac{R_2}{R_0} + \frac{R_0}{R_2} + \frac{X_2^2}{R_2R_0}\right)\sinh 2\alpha l \qquad (55)$$

When the reactive component of the load impedance is also negligible, the last term in the parenthesis drops out.

The last equation has been used to calculate the efficiency of transmission for several values of total attenuation for a range of values of mismatch. (Z_0/Z_2 or Z_2/Z_0 from 1 to 10) as shown in Figure 4. An important observation is that for a mismatch as large as 2/1, the efficiency is 90 per cent or more of the efficiency which could be obtained with perfect matching of characteristic and load impedances.

The curves of Figure 4 express only the increase in power losses in the line caused by standing waves on the line resulting from reflections at the load end. Unless the attenuation of the line is high, the

Calorimetric Method for Determining Efficiencies of Electric Machines

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AMONG the methods available for determining losses and efficiencies of electric machines, many have been developed to their utmost capabilities. Some measure individual losses separately and with good accuracy,[1–10] but many have inherent drawbacks. There still remains the desirability of a satisfactory over-all test which will rate the performance of all sizes of machinery under actual conditions of loading and yet yield highly accurate results. This aim is largely met by the calorimetric method and is justified by its basic character. A simplification of the classical testing technique can be introduced in which the important measurements are all electrical. By this means, accurate measurements of heat values are obviated, and the calorimeter becomes in reality only a comparator for a substitution process. Test results of calorimetric measurements on small induction and d-c motors show excellent agreement with other tests on the same machines. Analysis of the method indicates that it is equally applicable to all classes of machines of any size and that it can be used more generally for over-all loss and efficiency measurements under loaded conditions.

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Calorimetric Method

The classical form of the calorimetric method makes use of the basic principle that all losses are converted into heat. Measurements of thermal values from specific heat of the coolant, its volume, and temperature rise, have involved uncertainties and difficulties which have tended to discredit the method. However, these can be avoided by a simplification possible with electric machinery, in which the volume of the cooling medium is kept constant, and the temperature rise is measured under load and again with calibrating power input, thus giving a direct indication of the total losses within the system. The method is applicable to many types of machines, motor or generator, d-c or a-c, with only slight revisions in detail for each. Since total losses may be determined by it, and all other losses can be measured separately, stray load loss can be determined by this type of test. The American Standards Association Standards[3] and the test codes recognize the use of the calorimetric method, although reports of its use are rather scarce in the American literature. European tests reported to the International Electrotechnical Commission meetings at Prague in 1934 and Scheveningen in 1935 by the late Edouard Roth[2,11] show the development of simplifications in the calorimetric method. The procedure was to enclose the machine under test in a trunking or duct, through which a constant quantity of air was blown. Temperature rises from inlet to outlet were determined by the resistance of grids in the air stream, and losses to produce equal rises were introduced by means of heaters. Elaborate interpolation of data was required, because of difficulty in adjusting to exact equality.

Further extension of these simplifications is made in the tests being reported in this paper. Where possible, the calibrating losses are introduced directly into the machine under test so as to simulate actual losses exactly. A succession of points is taken so that a graphical determination of equal temperature-rise conditions may be made between the loaded and calibrating runs, thus minimizing the work of calibration. The use of differential thermocouples makes possible direct readings on a microammeter without the necessity of delicate potentiometer readings.

Equipment and Procedure

The test work was done on two machines, one an induction motor and the other a d-c motor of comparable size. The equipment consists principally of:

A double-walled calorimetric box of heat-insulating material to enclose the machine under test, in this case reversible so as to be usable on either end of the set.

A constant-speed blower to force air through the box.

Thermocouples differentially connected between inlet and outlet ports.

Power-measuring instruments in the leads to the test box.

Heaters inside the box near the test machine.

Figures 1 and 2 show the arrangement of parts.

The pair of machines is mounted on a wooden base with an iron subbase, and bolts are staggered so as to prevent any direct path of high thermal conductivity to the outside. A layer of insulating board is fitted around the machine feet, and the box is sealed to it. A slot on one side makes provision for a close-fitting air seal around the shaft, the coupling being outside of the enclosure. Dead air spaces

mismatch at the load end will affect the input impedance of the line, and in any practical case the coupling between the line and the generator will have to be adjusted to give the best power transfer.

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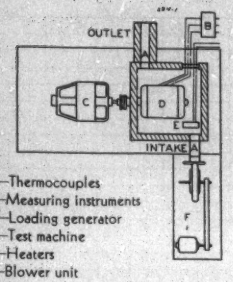

A—Thermocouples
B—Measuring instruments
C—Loading generator
D—Test machine
E—Heaters
F—Blower unit

Figure 1. Arrangement of calorimeter and machines

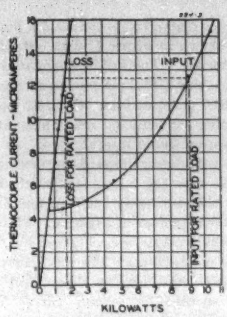

Figure 3. Temperature differences under load and calibrating conditions

Value of loss for corresponding input indicated by equal temperature differences

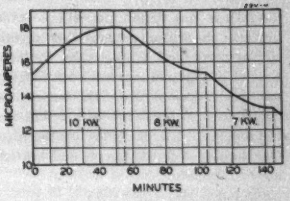

Figure 4. Typical temperature-difference curves for three values of total input to box with machine loaded

Readings taken at end of intervals

are filled with rock wool. A terminal plate provides electrical connections to the inside. Thermocouples are connected differentially in series between the blower pipe at the inlet and an insulated outlet at the diagonally opposite corner. Small ports are used to insure thorough mixing of the air, thus keeping all parts at a uniform temperature. This was verified by test and by observing the air stream through a window at the top of the box when smoke was injected.

As indicated in the introductory discussion, this method uses the calorimetric quantities for a comparison of the power values which will produce the same temperature conditions:

1. The machine is operated under load, and electric power input and thermocouple measurements are made. All losses of the machine, whether in electrical or mechanical form, are dissipated within this box and eventually contribute to the heating of the air. No measurement of shaft output is made unless desired as a check.

2. The coupling between machines is broken, and a set of measurements is made with the machine running idle to find the power input that is required to duplicate previous thermal conditions.

Finding the loss input which gives exactly the previous (loaded) temperature difference is unnecessarily tedious. For satisfactory results and minimum time used on a test, the better procedure is to take two curves of temperature difference (microamperes) for several values of heating, the air volume being held constant. One curve is taken as a function of total input under loaded conditions, and another is taken as a function of total losses. Such a set of curves is shown in Figure 3, with both curves plotted to the same scale for illustrative purposes. The total losses for any input are then determined from the curve of calibrating loss at the corresponding temperature difference. The machine output is found by subtraction and efficiency is computed in the usual manner.

As may be expected, time must be allowed for the thermocouple currents to become stabilized. Figure 4 shows typical curves for one run (air rate different from Figure 3). In the case of this thermal system, about one hour was required per reading, although this time could be shortened by changing the air rate during the transition period, gradually returning to the standard value. The air rate must be selected so that a total difference between inlet and outlet temperatures does not exceed about 20 degrees centigrade to approximate nominal ambient conditions. Since actual thermal values are not required, blower speed need be kept constant only during any one set of measurements. Air density and humidity should remain constant within the same period or not change appreciably. Inlet air temperature may vary slightly without error, but care should be taken to keep loading and control rheostats reasonably distant from the inlet. Because the method requires only repeatable conditions, even slight air leaks are not serious so long as they stay constant. Speed of the machine under test may vary slightly without serious error, due to changing the ventilation pattern within the calorimeter.

Up to this point, the procedure is perfectly general for any type of apparatus. The loaded temperature determination is likewise general, but consideration must now be given to methods of introducing the no-load or calibrating power into the calorimeter. The test machine is disconnected from the load, and it is allowed to run at its nominal speed. Additional heat may be introduced by heaters so placed that the internal ventilation will circulate the heated air. The calibrating power is thus the sum of the no-load input to the machine and the power to the heaters. In the case of induction machines, the entire power may be introduced into the machine by raising the applied voltage so that increased running-light losses will duplicate those at full load. This has the advantage of placing all the loss within the machine, although current

Figure 2. Calorimeter and machines

A—Thermocouples
B—Terminals for input and instruments
C—Loading generator
D—Test machine
E—Heaters
F—Blower unit

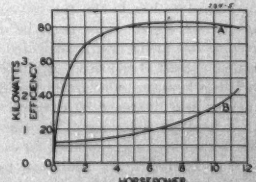

Figure 5. Total losses and efficiency at different loads derived from Figure 3

A—Per cent efficiency B—Total losses

limitations may require partial use of the heaters. Synchronous machines permit similar abnormal adjustments by field control of reactive currents, but it must not be overlooked that field copper loss contributes to the total heat within the calorimeter. D-c machines are the least amenable to this treatment, and heaters have to suffice.

Test on Induction Motor

An induction motor which had been thoroughly calibrated by many tests was available for test by the calorimetric method. This was fortunate, because the induction motor illustrates the good features of this test to the utmost, and illustrates the *method* well. In the calibration of the box, all of the necessary no-load losses can be confined to the machine itself by raising the applied voltage and exciting current until copper and rotational losses are of the order of total loaded losses, provided the stator current is not dangerously large. This permits the nearest approach to the ideal of having all losses identical in the two tests. The squirrel-cage machine used is rated 10 horsepower, 220/440 volts, 26.6/13.3 amperes, 60 cycles, 1,710 rpm squirrel-cage motor, and was operated at 220 volts.

Complete data were obtained from which separation of losses could be made, the calorimetric tests providing only the total loss value. Slip, stator resistance, and rotation losses were measured in addition to line current, voltage, and power usually measured in the efficiency test. Thermocouple current is the indication of temperature difference and is plotted in Figure 3 for the steady-state deflections given by a certain total input in the load run, and by a certain total loss input in the unloaded run. Since corresponding deflection currents indicate corresponding power values, the total loss for a given input is found by following across the proper ordinate to pick off the loss abscissa. The dotted lines indicate test data for rated load on the machine. It may be seen that deflection is proportional to loss in the box for constant blower speed. This is to be expected so long as the heat is dissipated in the same manner at all loads. As the box gets hotter however, other factors appear to permit heat to escape by conduction, with a resultant flattening of the curve. These make an actual calibration for each test very essential. An additional test using heaters for no-load input was made with identical results.

The final curves of total losses and efficiency derived from the data of Figure 3 are shown in Figure 5, with output as the abscissa. The full-load efficiency of this machine is 81.5 per cent as compared with 81.7 per cent from other test methods using conventional losses plus stray load loss measured separately.

As a demonstration of the accuracy possible with the calorimetric method, a set of values of stray load loss found by this test is plotted in Figure 6. The experimental points are obtained by two groups of observers. The solid curve is the stray load loss as determined by other methods,[4,5] several curves not widely different being averaged together. These results are quite consistent, especially when it is appreciated that stray load loss here is found as an indirect measurement by subtracting all other known losses from the total determined by the calorimetric method.

Test on D-C Machine

The calorimetric set used was reversible; so the box was turned around on the base, and measurements were made with the d-c machine as the test machine. The induction motor acting as a generator was loaded by operating it from a separate alternator. In this test, the calibrating losses were supplied by heaters in addition to the running-light input. The full-load efficiency by this method was 83.1 per cent, whereas the efficiency by conventional methods plus stray load loss[10] was 83.4 per cent.

Conclusions

The calorimetric method described in this paper consists of two fundamental steps only:

1. Determination of a temperature rise of the cooling medium under loaded conditions.
2. Substitution of an equivalent measurable loss which will produce the same temperature rise under no-load conditions.

This is a comparison or substitution method which determines with high accuracy the total losses of a machine under conditions of actual loading. The method permits good comparative data to be taken even under poor calorimetric conditions, although refinements improve the ease of obtaining good results.

Losses measured by it compare directly and favorably with those of other methods of high accuracy and show a final stray load-loss value very close to those from other tests. Although tests of only two machines are reported, the method has been demonstrated to be workable and fundamentally sound. Since it depends on a basic principle, the accuracy which may be expected will be determined by the care and techniques employed. Further attention to the calorimetric method will doubtless bring forth other advances in its use.

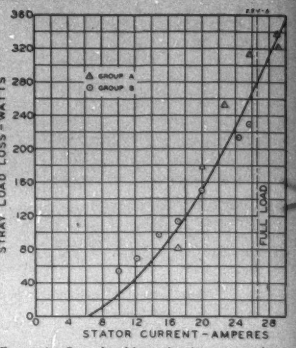

Figure 6. Stray load loss of induction machine tested

Solid curve average of tests by other methods.[5] Experimental points determined by calorimetric method by two groups of observers

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High-Voltage Fusing of Transformer Banks

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Synopsis: The paper summarizes some 15 years' experience with the high-side fusing of 11-, 22-, and some 66-kv transformer banks. The original purpose of fusing has through this experience been expanded to cover functions that are deemed desirable, and the authors feel that their approach to the specific protection field served by fuses has resulted in satisfactory protection at minimum cost.

The results of some faults occurring in fused and unfused banks are described briefly, and the various factors taken into consideration in selecting the proper fuse to use are discussed. The conclusions drawn are that fuses, when applicable, are a satisfactory economical means of obtaining reasonable coverage for faults in and beyond transformer banks.

THE experience of the Duquesne Light Company with what we shall call modern high-voltage power fuses began in 1926 when Schweitzer and Conrad liquid fuses were applied to the high-voltage side of several 22-kv banks in stations serving customers from a radial transmission line. The previous outages to this particular line were the determining factor in these fuse applications as an effort to improve service to the remainder of the line in cases of station trouble.

Early Experience

For the first few years our experience with these fuse installations was anything but satisfactory. These fuses deteriorated, causing uncalled for operations, and many justified blowings resulted in failures to clear, flashover of inadequate spacings, and flashover of inadequate insulators. These fuse operations were carefully followed, and such conditions of installation as contributed to unsatisfactory performance were eliminated. Mountings were replaced with higher insulation, spacing and clearances generally increased, and 34.5-kv fuses standardized upon for our 22-kv service. These changes, together with the manufacturers' changes of liquid, cap design, fuse element changes, and other advances, had made it possible to place considerable confidence in high-voltage fuses such that by 1937 our experience justified an extension of our fusing applications and the development of a general policy of fusing where applicable.

Experience up to 1937—Fused Versus Unfused Stations

By 1937 our number of fused banks had increased in proportion to our growing confidence in high-voltage fuses, and at that time we had 32 power applications in both customer and company distribution stations. An analysis of performance of fused and unfused stations for the years 1930 to 1937, as disclosed by fault records, brings out a striking comparison, and the records are tabulated in Table I for parallel consideration.

In the fused group we had had no fires, no explosions, no serious damage and, in many cases, immediate return to service of the faulted equipment, since prompt clearing had prevented permanent faults. Contrasted with this in the unfused group we had had three fires, one explosion, and had lost nineteen transformers such that they were either scrapped or completely rewound.

Origin of High-Voltage Fusing Policy

The original purpose of the high-side fusing of transformer banks was to minimize outages to multicustomer circuits where one customer fault would otherwise involve a total line outage.

An analysis of the above performance record disclosed that the fuses, in performing this original function, had provided additional benefits by preventing fires, explosions, or serious damage.

Based on this analysis, a policy has been established to provide adequate protection for all new bank installations and, over a period of years, to cover existing stations using fuses wherever applicable.

Experience 1937 to the Present

Our fuse installations now number well over 126, cover banks ranging in size from 50 kva at 22 kv, up to 10,000 kva at 66 kv, and involve the use of Schweitzer and Conrad types *D*, *C*, and *SM*, and Westinghouse type *BA*.

From 1937 to the present we have had 59 faults involving 87 fuse operations all functionally correct, and several of these,

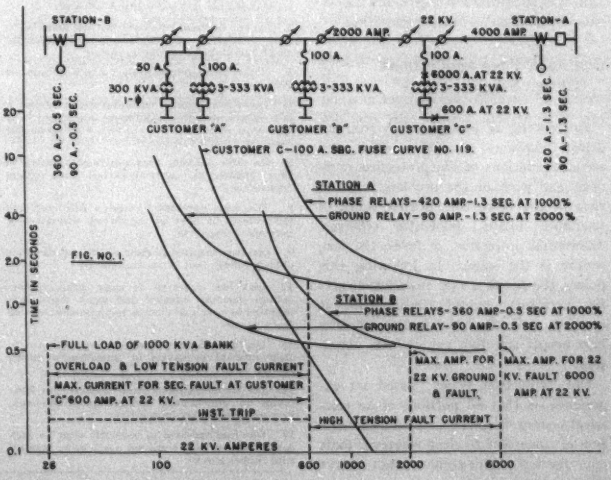

Figure 1. Selection curves of transmission-line relays, transformer-bank fuses, and low-voltage protection

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we feel, have avoided possible explosions and fires, and in addition, have prevented interruptions to other customers served from the lines involved. Many of these fuse operations have cleared low-voltage faults, where customer protection has been inadequate or inoperative, and where such faults could not have drawn sufficient current to operate the high-voltage protective relays until after winding breakdown. Such fuse operations have avoided transformer-winding burnout.

In one station fuses were used on each of four 10,000-kva, 66/11-kv transformer banks to avoid the installation of a high-voltage breaker and relaying, and, in final analysis, to give the customer better service. On two occasions these fuses have performed as intended, once by blowing to clear a fault not covered by the customer's low-voltage protection, and once by not blowing on a similar type of fault which was cleared by such protection. In the first instance high-voltage breaker protection would have given a complete interruption until performance of switching to segregate the defective low-voltage equipment, while the fuse application caused no interruption to three fourths of the service and segregated the fault promptly and properly.

The success we have had with our fuse installations has not been due alone to the improvement in the fuses themselves, nor to better installation conditions, but has been the result of these factors together with a judicious selection of the proper fuse for the existing conditions, and to a rigid inspection policy, and the practice of removing such fuses that give any indication of suspicion as to their condition.

Control of Fuse Applications (Design Stage)

In deciding all protective layouts, our design engineers seek the advice and recommendations of the protection engineer, and whether the problem involves that of the more complicated types of reactance relays, pilot-wire schemes, differential protection, or fuses, the procedure is the same. In following this policy, the simplest fuse installation gets the necessary careful consideration it requires, and all of the factors entering into proper selection get uniform attention.

Our protection policy, based on experience, is that all portions of an electrical system should be covered by protection of some sort to clear whatever fault may develop. This policy cannot always be met on an economically justified basis by relays and breakers. Where this condition is encountered, high-voltage fuses frequently provide a reasonably satisfactory solution.

Selection of Fuses for Transformer-Bank Protection

In selecting fuses for transformer-bank protection, investigation is made of the fault current obtained for faults, both on the high-voltage and low-voltage side of the transformer bank, and consideration is given to the protection that is provided on the low-voltage side of the transformer bank. A fuse is then selected with a time-current curve and a current-carrying capacity that will provide the desired time of operation for low-voltage faults.

In many cases, transformers that are fused supply industrial customers, and a variety of types of protection are used by the customer on his own breakers. Settings of these protective devices are determined, and high-voltage bank fuses are chosen to select with the low-voltage equipment. In some cases where customers' equipment is involved, it has been found that the protective equipment has been set unnecessarily high in current and time, and these settings have been lowered to the mutual advantage of the utility and the customer.

The fuse-current rating in relationship to full-load current of the protected transformers is not selected as any arbitrary value in relationship to the size of the transformer bank, but is selected as required with due consideration of the time-current characteristics of the different fuses available.

Since the application of these fuses is for the clearing of faults in and beyond the transformers, no attempt is made to protect the transformers against overloads. In this connection the current rating of fuses on our system varies from $1^1/_2$ to 4 times the bank full-load rating. The time delay and current-carrying capacity of the fuses are inseparable and are varied in order to obtain the necessary time delay for clearing of low-voltage faults. In practice the time delay provided for low-side faults varies from a minimum of 0.3 second on some lighting transformers to a maximum of 1.5 seconds on some power banks.

Time Selection of Fuses With High-Voltage Relays

While fuses are installed primarily to obtain clearing of faults in transformer-

Table I. Comparison of Performance of Fused and Unfused Substations

Fused Stations	Unfused Stations
1. Two fuses operated to clear a defective transformer caused by water entering the winding through a leaky low-voltage bushing.	1. Entire station, consisting of three 2/1 transformers and housing, destroyed by fire as result of transformer failure. Evidence of original failure lost.
2. All fuses operated to clear a defective bank of three 667-kva units during flood.	
3. One fuse operated to clear a failure of customer static capacitor on 2,300-volt side of bank.	2. Three 333-kva transformers destroyed, fortunately without fire, when a customer low-voltage fault held on, the customer's breaker found inoperative.
4. On two different occasions one fuse operated to clear a defective nonautomatic breaker bushing which had flashed over during storms.	
5. Three fuses operated to clear a high-voltage bus flashover.	3. Three 100-kva units destroyed, necessitating complete replacement as result of low-voltage winding failure.
6. Two fuses operated on initial cut-in to clear a low-voltage potential transformer which had been connected reversed with 115-volt winding on the customer's 2,300-volt bus.	4. Three transformers destroyed as result of low-voltage customer-equipment failure. Fault held on until breakdown of high-voltage winding, when 22-kv protective relays operated. Fortunately no fire.
7. On three different occasions fuses operated to clear trouble on customer-owned high-voltage transformers.	
8. Two fuses operated to clear a 2,300-volt bus fault caused by boys having thrown wire across a bare low-voltage bus.	5. Failure of one transformer resulted in oil fire which destroyed the entire station on customer premises.
9. One fuse operated to clear an internal flashover of high-voltage lead in one transformer.	
10. One fuse operated to clear defective low-voltage customer breaker and again three fuses operated to clear a flooded three-phase unit, leaving line in service.	6. Transformer failed and exploded at the station, resulting in fire which involved three other units and loss of all electrical equipment. Several intermittent grounds had been indicated at the supply station.
11. On four different occasions fuses operated to clear internal flashovers in transformers during storms.	
12. On three occasions fuses operated to clear faults on four-kilovolt circuit fed from bank. Low-voltage breaker inoperative.	7. Low-voltage disconnects pulled under load, fault held on until winding breakdown. Three 500-kva units complete winding loss.
13. One fuse operated to promptly clear an accidental contact with a ground chain being handled with rubber gloves.	8. On two occasions customer low-voltage cables caused failure of low-voltage bushings, due to fault hanging on and ultimately communicating to the high-voltage side of the bank.

bank windings or on secondary busses that would not otherwise be cleared properly, other benefits are sometimes obtained. These are:

(*a*). To prevent or decrease outages to other customers.

(*b*). To reduce damage to high-voltage bushings of transformers due to quick clearing.

In connection with item *a*, selection is not always obtained between the transformer fuses and the protective relays on the transmission system. In many cases, however, selection is obtained, particularly for short-circuit faults, and there are many instances where long outages to other tap or nonautomatic loop stations have been prevented by fuses clearing transformer faults before relays operated.

In some instances, the fuse and transmission-line relays may operate together, in which case the transmission line can be returned to service, as the fuses will have cleared the fault.

On many faults, however, the transmission-line ground relays do not select with fuses during line-to-ground faults, if the fault currents are of a low value. This nonselection is recognized and accepted.

With regard to item *b*, many transformer-bank high-voltage bushing flashovers have been cleared so quickly that service could be restored immediately.

Illustration of Specific Application

In Figure 1 is shown one example of application of fuses to three relatively small customers, supplied with tap service from a 22-kv loop circuit. In this particular case the distance between automatic stations is only about $1\frac{1}{2}$ miles and is close to a large 66/22-kv substation; as a result the current for 22-kv faults is relatively high.

Time-current curves of phase and ground relays at stations *A* and *B* and the melting time of fuses at customer *C* are shown. Maximum current of 6,000 amperes at 22 kv for a fault on the high-voltage side of transformer at customer *C* is indicated and a current of 600 amperes at 22 kv for fault on the low-voltage side of the same transformer.

These curves show that for a fault on the low-voltage side of the transformer at customer *C*, the melting time of a certain 100-ampere fuse is 0.45 second. This is adequate time to permit the low-voltage bank oil circuit breaker, with instantaneous trip coils, to operate. The curves also show that the phase relays at stations *A* and *B* select with this fuse at all current values. It is shown that the ground relays at the two stations do not select with the fuses at all currents. However, as the fault current is supplied from both ends of this circuit, the fuse obtains more current than either of the ground relays and may select. Also for any ground fault current above 1,000 amperes, the fuse will properly select with the ground relays. As it is possible to obtain 2,000 amperes ground current at this location, the probability of the ground relays selecting with the fuses is very good.

From the above it is seen that in this case the fuses not only serve to protect the transformer banks, but also to protect service to the adjacent customers.

The above illustration is only one of numerous similar conditions on our system.

Miscellaneous Factors to Be Considered in Applying Fuses

In applying fuses for the protection of transformers that supply various types of loads, different factors must be considered, depending on the type of load.

For example, fuses on the high-voltage side of a furnace transformer should have a continuous carrying capacity above the value of current that can be obtained for the condition of shorted electrodes in the furnace, as this is a condition that may exist for a considerable period of time during normal operation of the furnace. In this case, the fuses do not adequately protect the transformer bank in event of low-side failures, but do serve to disconnect the equipment from the system in event of severe faults in the furnace transformer.

In applying fuses for the protection of a transformer bank that supplies distribution circuits that are protected with oil circuit breakers, care must be taken to obtain sufficient time selection between the breaker opening and the blowing of fuse, so that the fuse will not operate incorrectly on normal reclosure of the oil circuit breaker on a faulted distribution circuit. Our present practice is to allow from 0.7 to 1.0 second selection between low-voltage reclosing feeder relaying and high-side bank fuses and while we have experienced no difficulty with this difference in selection, we realize it is open to question and to reconsideration as experience requires.

Conclusion

It is not intended to convey the impression that high-voltage fuses should be used for the protection of transformer banks in preference to relays and oil circuit breakers. Where this equipment is available or can be justified, it should be used. In many cases, the cost of oil circuit breakers cannot be justified, and in such cases, fuses, if applicable, can be used.

In general, it is felt that, in the voltage range of our experience, the modern high-voltage fuse, properly applied and not forgotten, is a reliable protective device that should be added to the other protective schemes, and that it has a definite place in meeting requirements at moderate cost that cannot otherwise be economically justified.

A 600-Volt Enclosed Limiter for Network Use

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Synopsis: The extension of the conventional network system to industrial plants has established requirements for a higher-voltage limiter.

The network system has been adopted as a standard by many utilities for 120–208-volt distribution, whereas industrial-plant distribution is usually at higher voltages up to 600 volts due to the predominance of power load. The requirements of a limiter for this service are more severe, due to the proximity of operating personnel and increased interrupting duty associated with higher voltages and shorter cable runs.

A new totally enclosed limiter has been developed for this application. This limiter embodies new principles of operation and will interrupt fault currents in excess of 50,000 amperes at 600 volts without perceptible noise or visible demonstration.

NETWORK systems as originally conceived and installed did not make use of limiters, for the systems were based on the premise that cable-insulation failures encountered on 120–208-volt circuits would be self-clearing. Experience has proved this premise to be generally correct.[1] Obviously, however, there can be solid metal-to-metal faults that are not self-clearing. Furthermore, faults, although self-clearing, could persist until heating of the cable resulted in permanent damage to the cable insulation. Usually, such persistent faults would spread to adjacent cables, materially increasing the resultant damage. The large amount of power liberated in these extensive faults often produced combustible gases in sufficient quantities to cause manhole explosions.[2] These factors led to the development of the limiter which consists of a fusible section located at the ends of cable runs to guarantee the clearing of any fault on the cable before its insulation is damaged or the fault spreads to other cables. The correct analysis and solution of this problem is due largely to the work of C. P. Xenis of the Consolidated Edison Company of New York.[3]

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Limiters have been in service on 120–208-volt network systems for several years and have been found ideal for the application.[4] Factors contributing to the rapid adoption of limiters on network systems are as follows:

1. The limiter requires no maintenance. It has no contacts or adjustments and consists of a simple conductor having swedged or bolted connections. It can be connected into the cable and forgotten. The rapid adoption of the limiter has been due principally to this one factor of simplicity and reliability.

2. It eliminates damage to unfaulted portions of the cable. Being a thermal device, it is ideally suited to the protection of cable insulation from heating due to fault currents.[5]

3. The limiter insures the rapid clearing of heavy fault currents, thereby minimizing system disturbances and localizing all faults.

4. In networks having two or more cables per phase, proper selectivity between limiters is automatic. Co-ordination with network protector fuses can be easily obtained by proper planning.[6,7]

5. A quick reclosing device in place of the limiter would be of no particular benefit, for considerable maintenance must be performed on the cable after a fault.

6. The limiter is relatively inexpensive and renders a service out of all proportion to its cost. It may be used at both ends of all cables. Consequently, a fault will disable only a short section of cable.

Previous Limiters

Until the advent of industrial networks the application of limiters was confined almost exclusively to 120–208-volt networks for city distribution. The requirements of limiters connected in these systems were not too severe. The low system voltage combined with short-circuit currents which seldom reached 30,000 amperes represented moderate interruption duty. Since the limiters were usually placed in underground vaults, there were no strict requirements on noise or demonstration. In addition, the limiters were not the only line of defense, for most faults at this low voltage are self-clearing.

The limiter developed for this service consists of a reduced metallic or fusible section incorporated in a connector lug

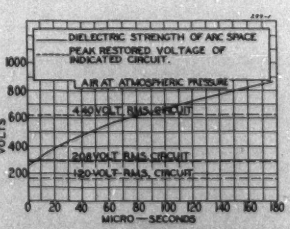


Figure 1. Recovery of dielectric strength of arc space of short arcs with reference to the peak restored voltage of standard systems

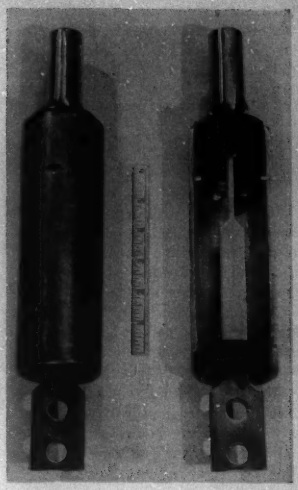


Figure 2. Assembled and sectional view of new limiter

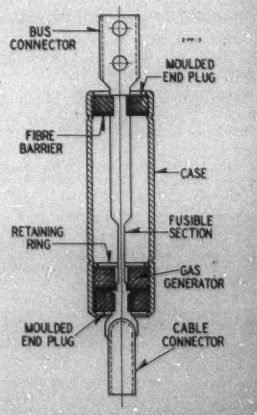


Figure 3. Cross section of new limiter

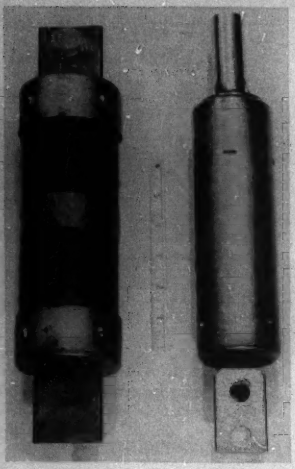


Figure 4 (left). Comparison of new limiter with cartridge fuse

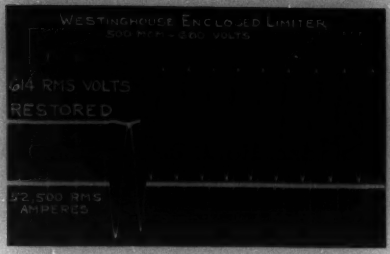


Figure 6 (right). Interruption of current above rating

or other connecting device. The fusible section is surrounded with heat-resistant insulation, and the whole assembly is placed in a rubber sleeve and securely taped to prevent the escape of hot gases or flame during interruption. These limiters, when operating within their current and voltage limits, have given successful interruptions without demonstration. They have been found admirably suited to the service for which they were designed.

Requirements for a New Limiter

The entrance of the network distribution system into the industrial field created several new problems. Systems up to 600 volts were encountered, cable runs were considerably shorter, and power concentrations were greater. All of this led to greatly increased short-circuit currents which had to be interrupted at these higher voltages. Under these conditions, faults are seldom self-clearing.[8] Referring to Figure 1, it is seen that an arc space recovers a dielectric strength of about 250 volts instantly at current zero. This is sufficient to cause interruption of arcs on a 120–208-volt circuit. Considerable time is required for the arc space to recover sufficient dielectric strength to cause circuit interruption at higher voltages; hence, faults on a 440-volt system must be cleared by an interrupting device. Limiters, therefore, were necessary to guarantee the interruption of the circuit. Strict requirements concerning noise and demonstration were imposed on the limiters, because they were required to operate in close proximity to factory personnel. Furthermore, the limiters for industrial application could not present any fire hazard whatsoever.

In accordance with these requirements, it was decided that a limiter for this new service should have the following characteristics:

1. It must be totally enclosed and have minimum space requirements.
2. It must have an interrupting rating of 50,000 amperes at 600 volts, 60 cycles.
3. It must have a low temperature rise to permit bunching of limiters in confined spaces.
4. It must have a time-current characteristic to permit co-ordination with other limiters, co-ordination with its cable insulation, and co-ordination with the network protector fuses.
5. It must have suitable terminals to permit coupling with the proper cable.

Design of a 600-Volt Limiter

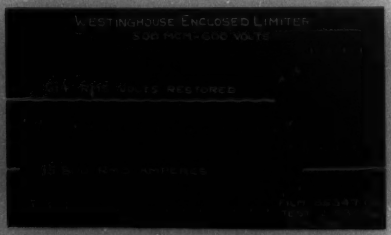
The design of a totally enclosed limiter of the required small size presented the dilemma usually associated with engineering problems. On one hand the device must have five times the interrupting ability of a cartridge fuse of comparable current rating, and on the other hand, not only must it be made smaller, but the demonstration attendant to circuit interruption must be eliminated.

The design was accomplished by solving two problems:

1. The metallic vapors and gases from the heavy fusible element had to be accommodated. Tests revealed that a copper sheath or cover around the fusible element would supply a condensing surface on which the fused metal would be deposited, thus eliminating high internal pressures.
2. Totally enclosed interrupting means had to be provided to insure positive interruption of all currents up to the interrupting rating. Further development evolved a concentric fiber gas generator, which would supply the necessary turbulence to cause deionization of the arc.

Figures 2 and 3 show the final design of the limiter. The conducting element is made from copper tubing which is

Figure 5. Interruption of moderate current



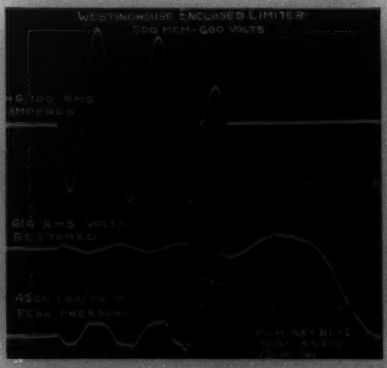


Figure 7 (right). Pressure record during interruption by new limiter of fault current near rating

The pressure variations preceding the melting of the fusible section are induced but are not present after the current is interrupted

Figure 8. View of limiter cut open after interrupting moderate current

Note deposition of copper on inside surface of case

flattened and sized to produce the proper fusible element and terminal connectors. The closure plugs are moulded on the conducting element in an extrusion-type mould with the retaining ring in place. Split fiber washers are used as barriers to prevent arc flame from burning the moulded material and to produce the gas generating structure. This structure is held from moving under the stress of interruption by the retaining ring which fits up against embossed shoulders on the outside casing. A copper tube forms the case of the limiter and in addition furnishes the condensing surface for the metal vapors. The conducting element is restrained from sliding by embossing the copper tubing, after which the entire assembly is sealed by swedging in the ends of the case. Figure 4 compares the size of the limiter with a 600-volt cartridge fuse of the same current-carrying ability.

Tests

Repeated interruption tests were made throughout the entire current range. In many tests, the limiter was completely surrounded by surgical cotton in accordance with the procedure established by the Underwriters' Laboratories, Inc. In no test was the cotton discolored, thus proving the absence of flame or hot gases external to the limiter. Figure 5 is an oscillogram showing an interruption at a moderate current value. In Figure 6 the interruption of a current in excess of the rating of the limiter is shown. Note the shift in power factor of the circuit caused by the relatively high arc voltage. This characteristic of the limiter is an advantage in that it aids in the interruption of the circuit and protects the system from voltage stresses. Internal pressure is recorded on the oscillogram in Figure 7. The short duration of the pressure is caused by the rapid condensation of the metallic vapor by the copper case and by the cooling of the generated gas. The condensed metal vapor is seen in Figure 8 as irregularities on the inside surface of the blown limiter. Voltage tests were made on blown limiters by putting them on overvoltage immediately after interruption. In all cases the limiters withstood voltages above 2,200 volts continuously for several days until removed from test.

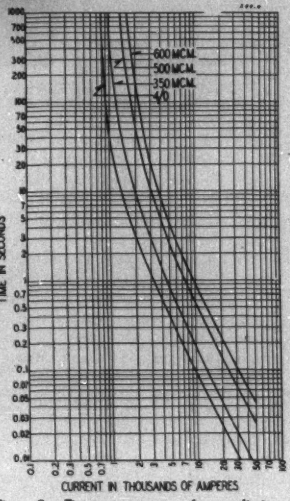


Figure 9. Time–current curves for new limiter

The limiter is designated by the size of cable for which it is intended

The sizes of fusible elements were determined by the co-ordination requirements. Time-current curves for several common sizes are shown in Figure 9. A study of the curves will reveal that any one limiter will be blown without damage to the other limiters on the system, if the fault current is fed to the limiter which interrupts the circuit through at least two other limiters in parallel. This is the case in a properly designed network system, where there are two or more cables per phase, as will be seen by reference to Figure 10, a schematic diagram of a typical load bus unit.

Temperature-rise tests were made with the limiter connected to the supply by eight-foot lengths of the proper size type-*R* cable. The limiter was supported in free air and was shielded from air currents by a canvas screen placed completely around the device. Temperature rises were found to be less than 30 degrees centigrade for all sizes at the maximum current ratings of the cable.

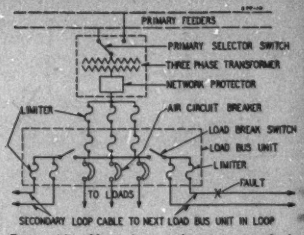


Figure 10. Unit of network system in which selectivity between limiters is automatic

Note that current flows in parallel through all other limiters on the bus to the limiter clearing the fault

Conclusions

Past experience has shown the desirability of a network system and the effectiveness of limiters in providing the proper protection. The new 600-volt limiter described in this paper is serving in a number of industrial plants at the present time, and all experience has been satisfactory. In addition, extensive laboratory testing has adequately proved the new limiter's ability to perform its functions. There has been provided a new 600-volt limiter, small in size, but capable of interrupting large currents without perceptible noise or visible demonstration.

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